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Photointerpretation Guide for Identifying Pines Killed by the Mountain Pine Beetle

METHODS APPLICATION GROUP
REGION 2, FOREST PEST MANAGEMENT
NATIONWIDE FORESTRY APPLICATIONS PROGRAM

PHOTOINTERPRETATION GUIDE FOR IDENTIFYING PINES KILLED BY THE MOUNTAIN PINE BEETLE

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Houston, Texas

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INTRODUCTION

Destructive insects and diseases are major factors affecting the productivity of forest lands in the United States. In support of pest management activities, data are needed on the locations of existing or potential outbreaks and the volumes of timber lost because of infestation. These data will be used in determining where to direct control efforts, in identifying stands where preventative action should be taken, and in adjusting forest yield projections.

In order to provide these data, survey methods must be available for acquiring data within the short time period when the signs and symptoms of pest activity are visible. In recent years, high-resolution panoramic aerial photography taken from reconnaissance altitudes (60,000 feet above ground level) has been shown to be an effective means of acquiring data for at least one major forest insect pest, the mountain pine beetle (*Dendroctonus ponderosae* Hopkins).

The photographic characteristics of two major host trees killed by the mountain pine beetle are illustrated in this guide. The two hosts are ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*). These photographic characteristics have been developed from high-altitude panoramic aerial photography and are applicable throughout the insect's natural range in the Western United States.

Much of the information presented on ponderosa pine was generated from two surveys on mountain pine beetle infestation conducted in the Front Range of Colorado (refs. 1, 2). The 2 years of photointerpretation experience gained from these surveys forms the basis for the techniques presented in this manual. These techniques are applicable for surveys of other areas by considering examples in light of regional differences.

A comparison is also made between ponderosa pine in the Front Range of Colorado and in the Black Hills National Forest of South Dakota. This distinction seems appropriate since ponderosa pine along the Front Range is interspersed with other tree species and displays a mottled density atypical of the uniform stocking of the species in the Black Hills.

The most thorough evaluation of losses in lodgepole pine was by Klein et al. (ref. 3) in the Beaverhead and Gallatin National Forests, Montana.

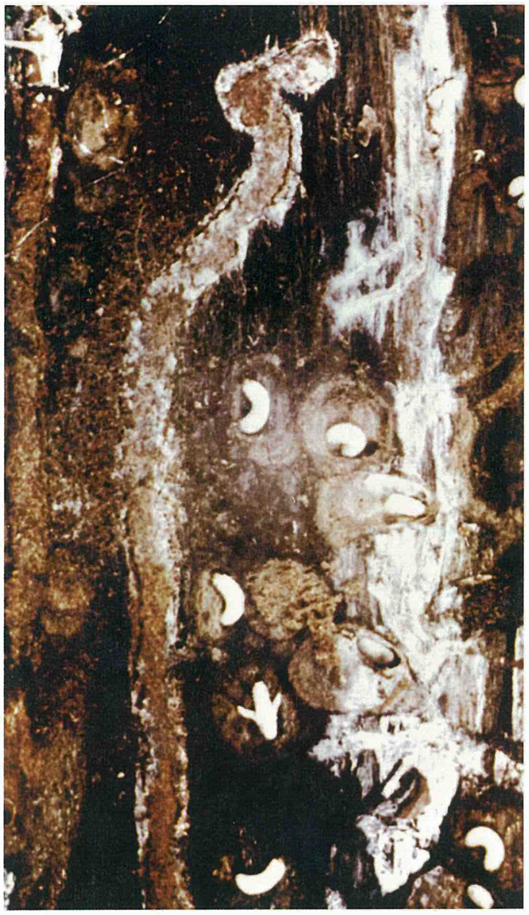
This guide can be used as a formal training package during the photointerpretation phase of future surveys involving ponderosa pine and lodgepole pine. In addition, it can be used in conjunction with the final report on the 1980 mountain pine beetle survey in the Front Range of Colorado (ref. 1) or with similar reports (e.g., ref. 3) to form the basis of a contractual package for future surveys.

MOUNTAIN PINE BEETLE

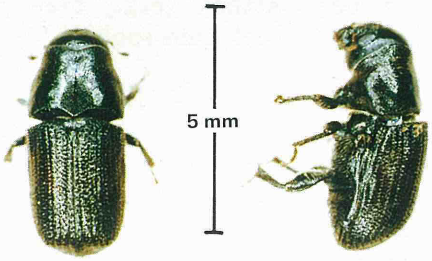
In the Western United States, the mountain pine beetle is the most destructive forest insect pest affecting ponderosa pine and lodgepole pine. In epidemic proportions, it is capable of destroying millions of cubic feet of timber.

To better understand the features that one is looking for on a photograph with respect to trees killed by the mountain pine beetle, familiarization with the life cycle of the pest is helpful. These life stages bring about the host's expression of pest attack (e.g., tree fading, which is the usual clue looked for on the film).

The typical 1-year life cycle of the mountain pine beetle consists of four stages: egg, larva, pupa, and adult (fig. 1). All stages are spent under the bark of infested trees, with the exception of a few days when adults emerge and fly to new trees. Colonizing flights occur any time from June to September.



(a) Galleries with larvae and pupae; some adult beetles present.



(b) Adult beetles.

Figure 1.- Examples of the mountain pine beetle life stages.

The mountain pine beetle attacks trees of all sizes but prefers those larger than pole size (9-inch diameter at breast height) or occasionally overmature ones. Trees that are successfully attacked by this pest display the following symptoms and signs (ref. 4):

- Boring dust - orange to cream-colored particles of bark and wood in crevices and at base of tree (fig. 2a).
- Pitch tubes - dark-red to cream-colored masses of resin mixed with bark and wood borings issuing from the point of attack (fig. 2b).
- Entrance holes - 3-millimeter circular holes in the bark where the adult beetle entered the tree.
- Galleries - long, nearly straight, vertical frass-packed constructions in the soft inner bark which slightly scar the sapwood (fig. 1a).
- Discolored foliage - fading and changing color of needles on successfully infested trees usually occurring in the spring following attack. The sequence of color changes is green to greenish yellow, orange, and finally red and rusty brown (fig. 2c).
- Blue-stain discoloration - a blue stain on the wood just under the bark appearing a few weeks after a successful attack. This stain is caused by fungi that the beetles carry into the trees on their bodies. The fungi cause the death of the tree by clogging its water-conducting vessels (fig. 2d).

Trees infested in the summer of one year (e.g., 1980) show the effects in the summer of the following year (1981). These trees are referred to as "current-year faders"[1] as opposed to "old faders" from previous years.

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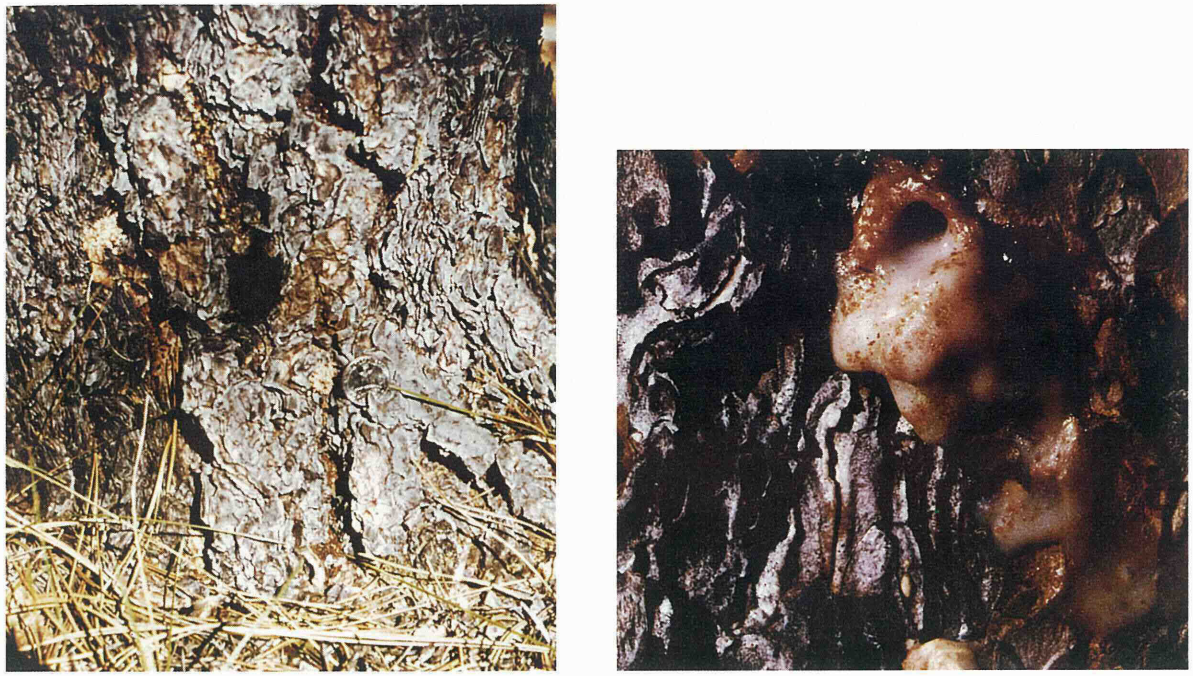
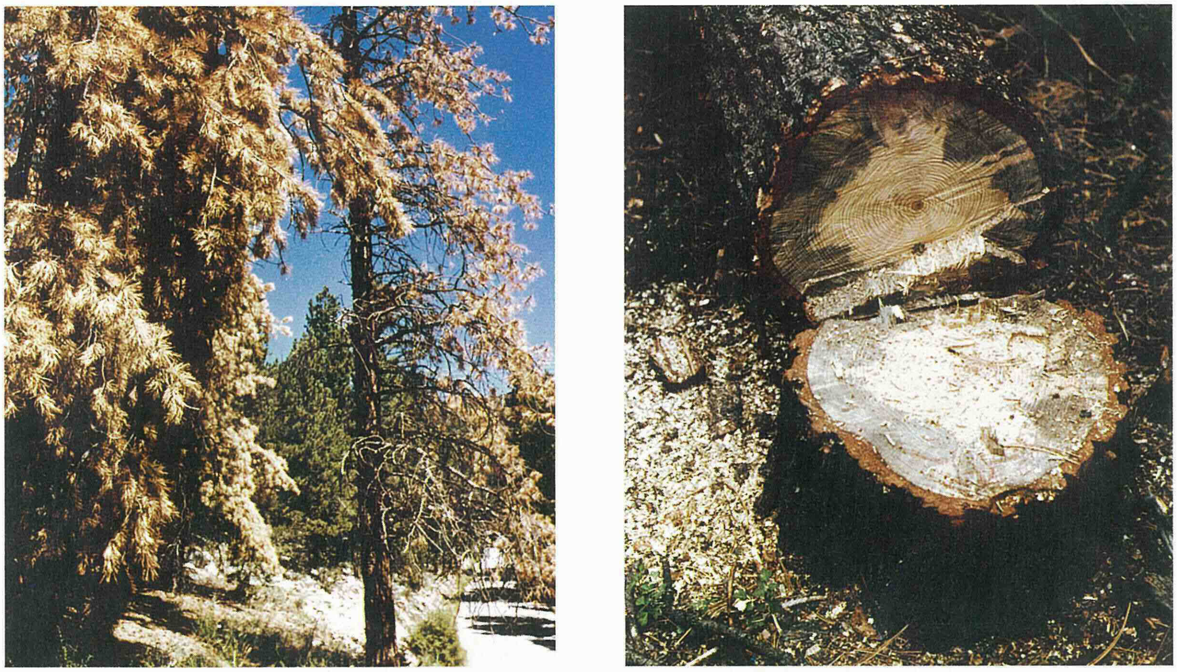
[1] The term "fader" is a colloquial expression for a conifer tree having a discolored (yellow/orange) appearance which results from attack by mountain pine beetles.



(a) Boring dust at base of tree.

(b) Pitch tubes.



(c) Discolored foliage.

(d) Blue-stain discoloration.

Figure 2.- Visual symptoms of mountain pine beetle attack.

PRINCIPAL HOST SPECIES

Mountain pine beetle attacks on a variety of pines native to the Western United States have been recorded. These pines include ponderosa, lodgepole, western white (*Pinus monticola* Dougl. ex D. Don), sugar (*Pinus lambertiana* Dougl.), limber (*Pinus flexilis* James), and whitebark (*Pinus albicaulis* Engelm.) pines. The two primary host species for the mountain pine beetle are ponderosa pine and lodgepole pine. A mixed stand of infested ponderosa pine and lodgepole pine near Glacier National Park, Montana, is shown in figure 3; mature pines of these two species which were grown in open areas are pictured in figure 4.

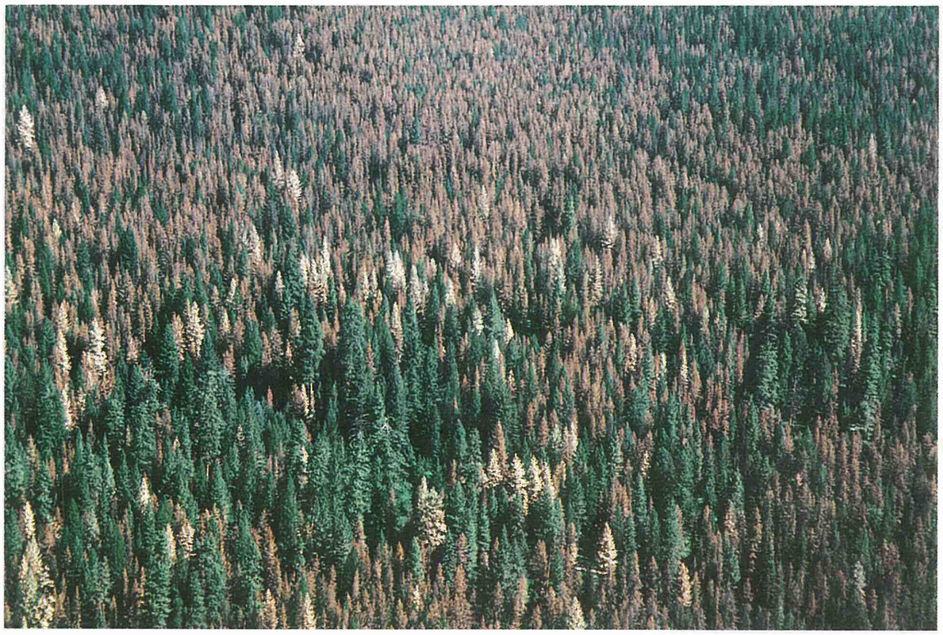
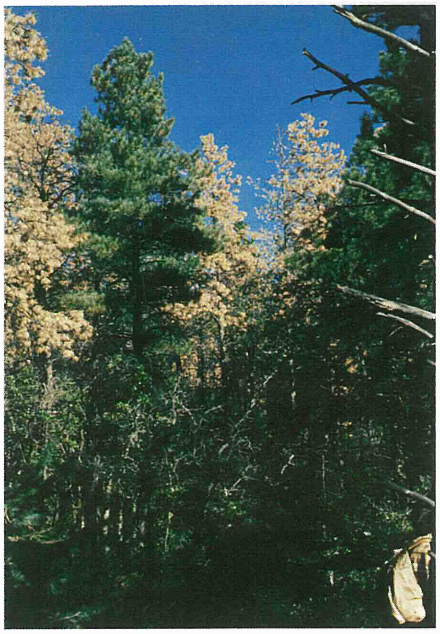
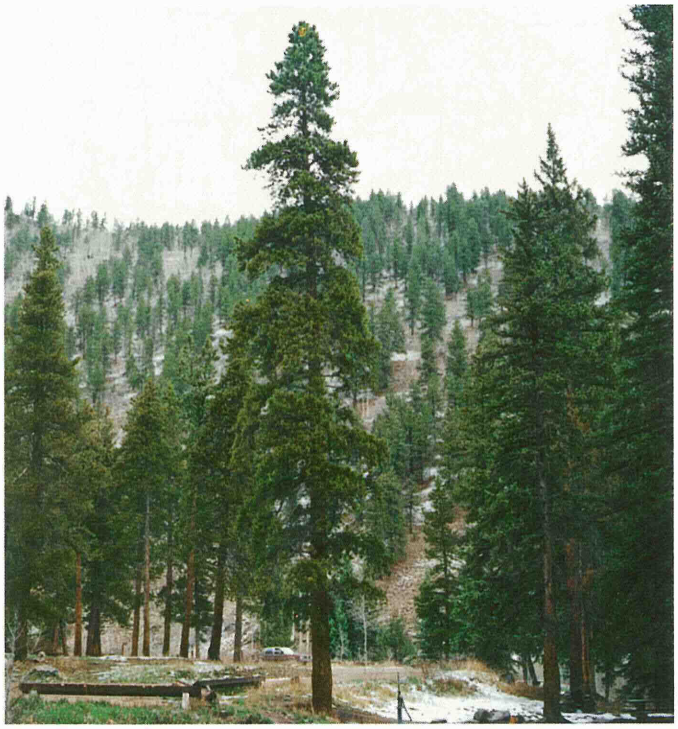


Figure 3.-Mountain pine beetle infestation in a ponderosa pine and lodgepole pine stand near Glacier National Park, Montana.



(a) Ponderosa pine.

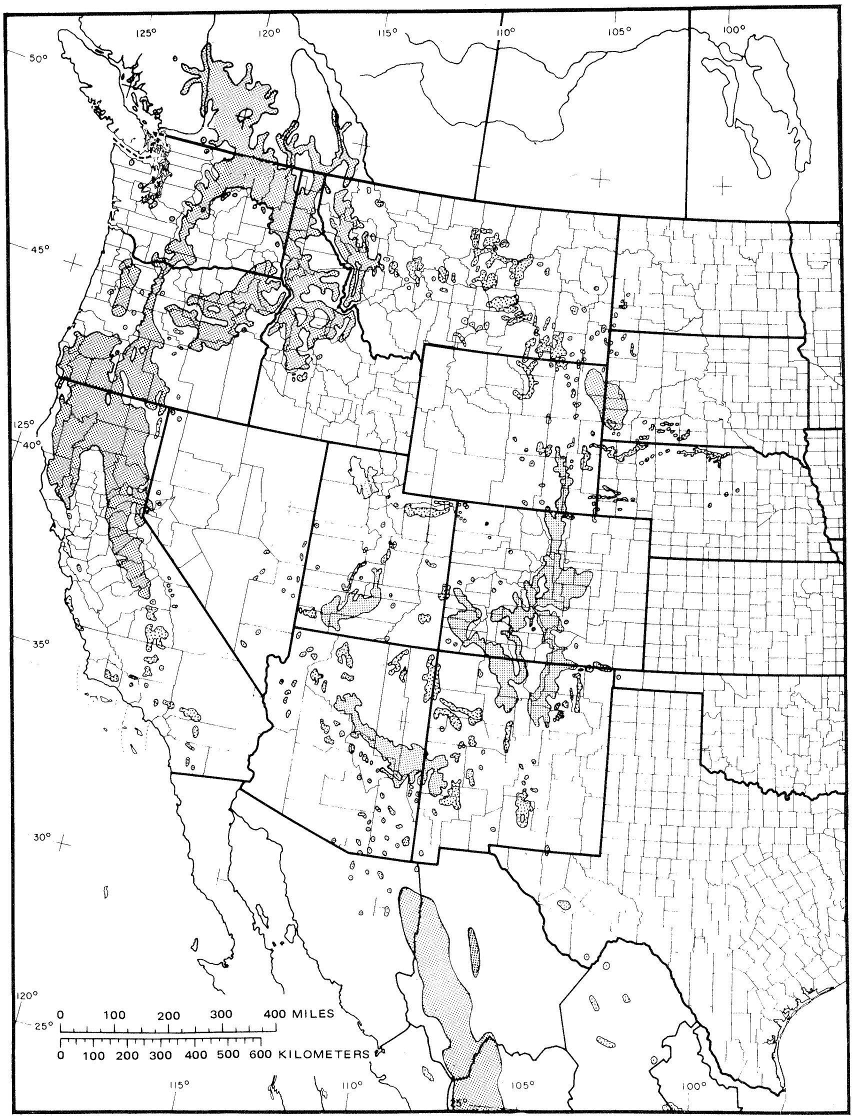


(b) Lodgepole pine.

Figure 4.- Mature ponderosa pine and lodgepole pine grown in open areas.

Ponderosa Pine

Ponderosa pine is a long-needled pine with needles 5 to 8 inches in length. Its distribution throughout the Western United States is shown in figure 5. It grows in native stands at elevations from sea level to 9500 feet. At lower elevations, ponderosa pine can be found in pure stands; toward its upper elevational limits, it is found mixed with Douglas-fir and other conifers. These stands vary from open park-like stands to dense patches of trees. The more open stands have a light-to-moderate herbaceous plant density under the forest canopy. Individual trees can become quite large, reaching diameters of 30 inches or more and heights of over 100 feet. The crowns of mature trees tend to become flat at the top (fig. 4a).


125°
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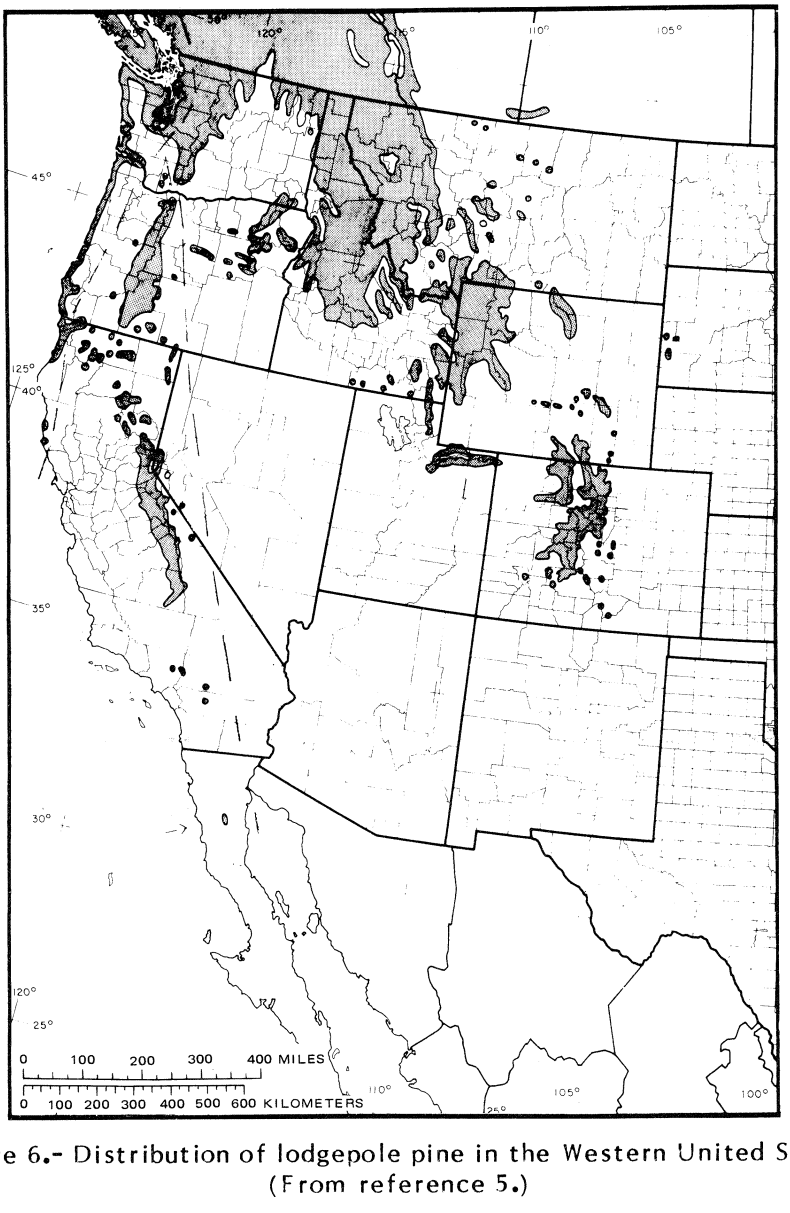
40°
35°
30°
120°
25°
0 100 200 300 400 MILES
0 100 200 300 400 500 600 KILOMETERS
115°
110°
105°
100°
25°

Figure 5.- Distribution of ponderosa pine in the Western United States. (From reference 5.)

Lodgepole Pine

Lodgepole pine is a short-needled pine with needles 1 to 3 inches in length. Its distribution throughout the Western United States is shown in figure 6. It is found in native stands at elevations from sea level to 11,500 feet. Most native stands are dense and contain even-aged trees. The closed canopy causes a forest floor with little herbaceous vegetation. Individual trees of small-pole size and larger appear tall and straight with a relatively clear bole and a short, narrow crown (fig. 4b).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0 100 200 300 400 500 600 KILOMETERS
110°
105°
100°
25°

Figure 6.- Distribution of lodgepole pine in the Western United States. (From reference 5.)

PANORAMIC PHOTOGRAPHY

Camera

An aerial panoramic camera achieves large-area coverage at high resolution by using only the center of a lens with a narrow field of view and sweeping the lens across the terrain, perpendicular to the line of flight. The effective projection of the ground plane onto the cylindrical film platen by the lens produces a decreasing scale away from nadir. This variation in scale is known as panoramic distortion. That is, scale decreases and obliquity increases outward from nadir (fig. 7).

The Itek KA-80A optical bar camera uses standard 5-inch-wide film to produce 4.5- by 50.26-inch images. The lateral coverage is 120° (60° to each side of nadir). When flown at 60,000 feet above the ground level, the camera focal length of 24 inches produces photography with scales of 1:30,000 at nadir and 1:60,000 at the edge of the frame. The panoramic photography covers a distance of 1.85 nautical miles at nadir and 3.7 nautical miles at the edge of the film. The cross-track coverage is 34.2 nautical miles. (See appendix A.) The effective working angle is normally ±40° to either side of nadir. This is caused by the decreasing scale, increasing image obliquity, and color attenuation problems at wide viewing angles; i.e., greater than 40°.

The resolution of the image is theoretically constant even though the scale varies as the distance from nadir increases (ref. 6). In an empirical study, the resolution of Itek KA-80A color infrared photography was measured using standard military resolution targets (ref. 7). With a nadir scale of 1:30,000, there was no loss of resolution with increasing distance from nadir. A photo-interpreter was able to distinguish objects 2 feet wide at nadir and objects 4 feet wide at the limit of scan (60°).

The Itek KA-80A optical bar camera can carry approximately 6500 feet of film, which will provide coverage of about 1250 nautical miles or 1480 frames of photography when flown at 60,000 feet above the ground level.

The Itek IRIS II panoramic camera is currently being tested. This camera is similar to the Itek KA-80A camera with the following exceptions: The scan angle can be set at 70° or 45° to either side of nadir, and the theoretical resolution is less than 2 feet at nadir.*

Aircraft

Aerial photographic missions using the Itek KA-80A panoramic camera are normally flown by the National Aeronautics and Space Administration (NASA) U-2C or ER-2 aircraft. The U-2C (fig. 8) is a one-man aircraft designed and built by Lockheed Aircraft Corporation for high-altitude, long-range operations. It is stationed at the NASA Ames Research Center at Moffett Field, California. Based on a flight time of 6 hours and a speed of 400 knots, its operational range is normally about 1200 nautical miles; however, coverage may be extended by deploying the aircraft to another airfield.

The NASA ER-2, a research version of the U.S. Air Force TR-1 tactical reconnaissance aircraft, is designed to cruise above 70,000 feet at a speed of 478 knots. It has an operational range of more than 3000 nautical miles and the capacity to carry three times the payload of the U-2C.

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*The use of trade and company names is for the convenience of the reader and does not imply endorsement by the U.S. Department of Agriculture or its contributors.

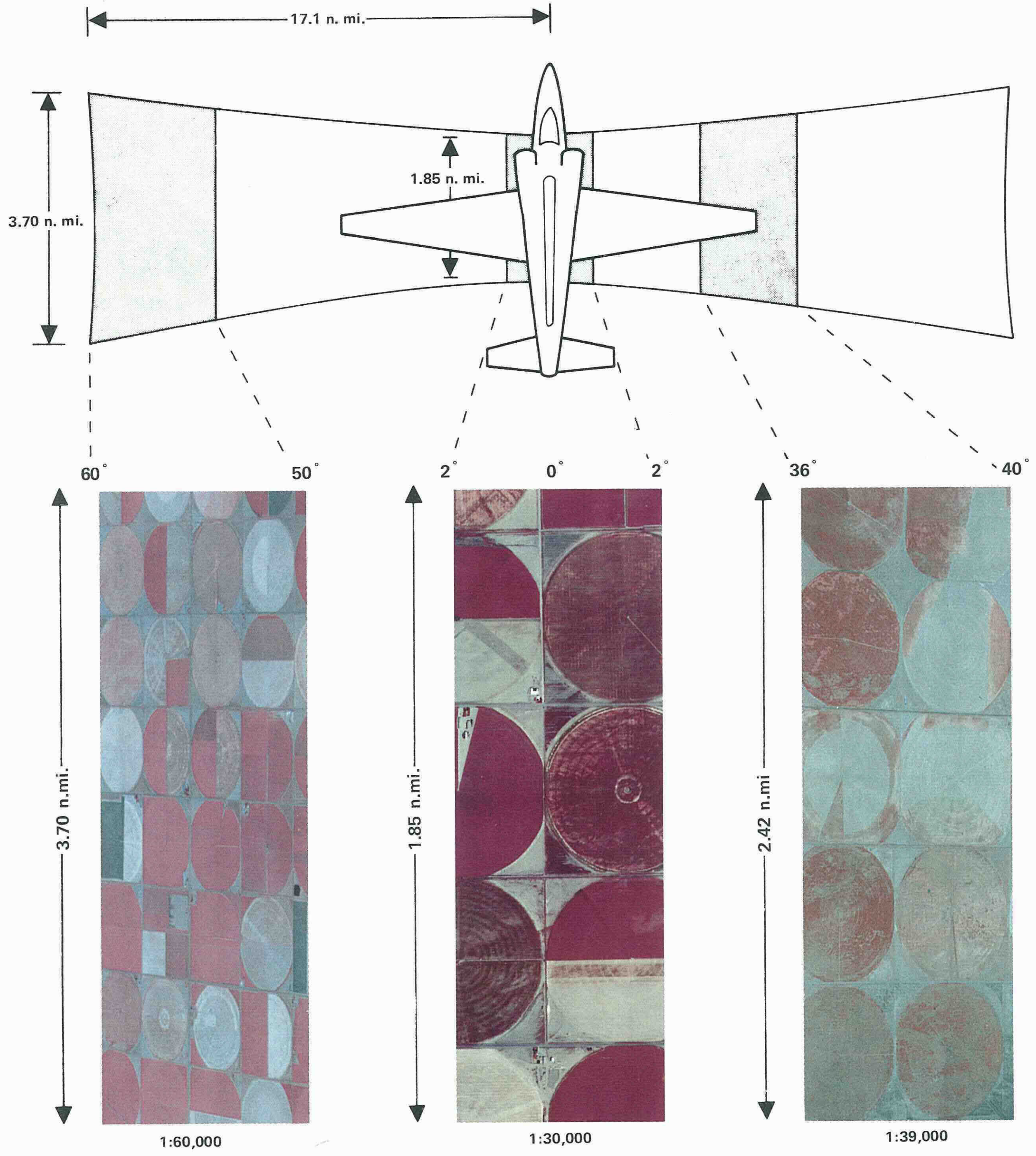

17.1 n. mi.
3.70 n. mi.
1.85 n. mi.
60°
50°
2°
0°
2°
36°
40°
3.70 n.mi.
1.85 n.mi.
2.42 n.mi
1:60,000
1:30,000
1:39,000

Figure 7.- Area coverage and panoramic distortion of Itek KA-80A photography at 60,000 feet above ground level. Circular irrigation systems are 0.5 mile in diameter.

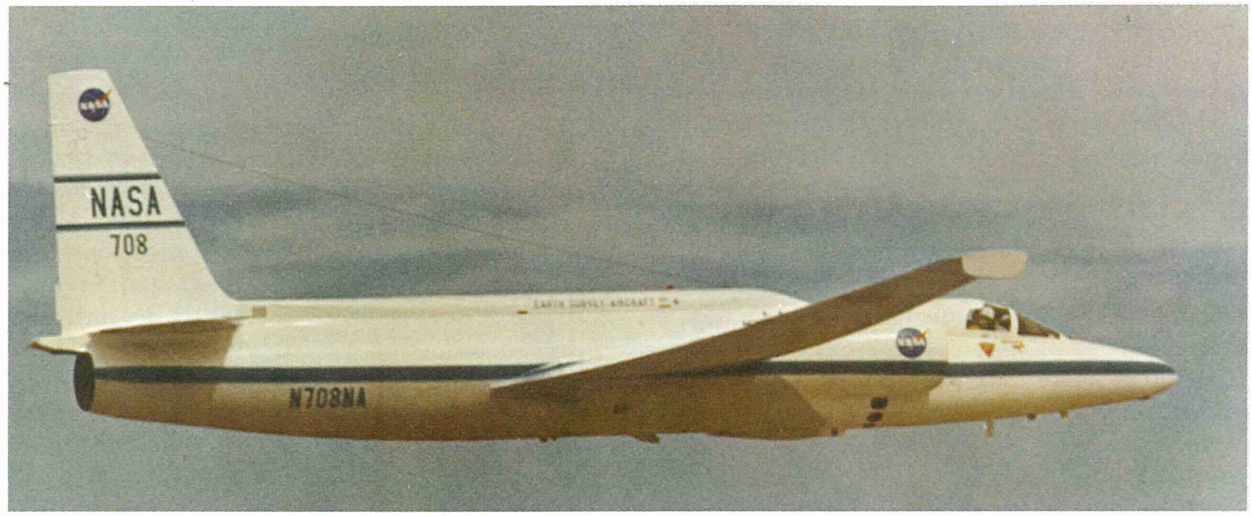


Figure 8.- NASA U-2C aircraft used to collect high-altitude panoramic photography.

Color Infrared Film

Color infrared film has been selected for use in acquiring high-altitude photography in support of insect damage surveys mainly because of its ability to penetrate haze, to differentiate between conifers and hardwoods, and to provide good color contrast between dying and healthy trees (ref. 8). Haze is caused by scattering of light as it passes through the atmosphere and is reflected from the Earth's surface. The amount of atmospheric scattering depends on both the number of gas molecules and the number of larger particles (Mie particles) that are present. The larger particles include dust, water, and smoke (ref. 9). The gas molecules scatter light at a rate inversely proportional to the fourth power of the wavelength; i.e., Rayleigh effect. This means that blue and ultraviolet wavelengths are scattered more than are red and near-infrared wavelengths. The Mie particles have a similar effect. With most of the gas molecules and Mie particles located below the 60,000-foot flying height of the U-2C aircraft, haze is a major problem.

Color infrared film with a yellow Wratten 12 filter is designed to be sensitive in the 0.5- to 0.9-micrometer spectral range. Because the blue and blue-green wavelengths are not recorded by the infrared film, excellent haze penetration is achieved.

Color infrared films, such as Aerochrome high-definition infrared film (SO-131), have been designed to cause healthy vegetation to exhibit a strong photographic contrast with respect to other features. Since the film is normally exposed through a Wratten 12 or 15 filter, blue light does not contribute to the formation of the image. The three dyes of the film respond to green, red, and infrared wavelengths (fig. 9). The net result is that green objects, except vegetation which is highly reflective in the infrared, appear blue; red objects appear green to yellow; and infrared-reflective objects (healthy vegetation) appear red.

An understanding of how the image color is formed on color infrared film is important in interpreting familiar features and in analyzing unknown features. Aerochrome color infrared film is a

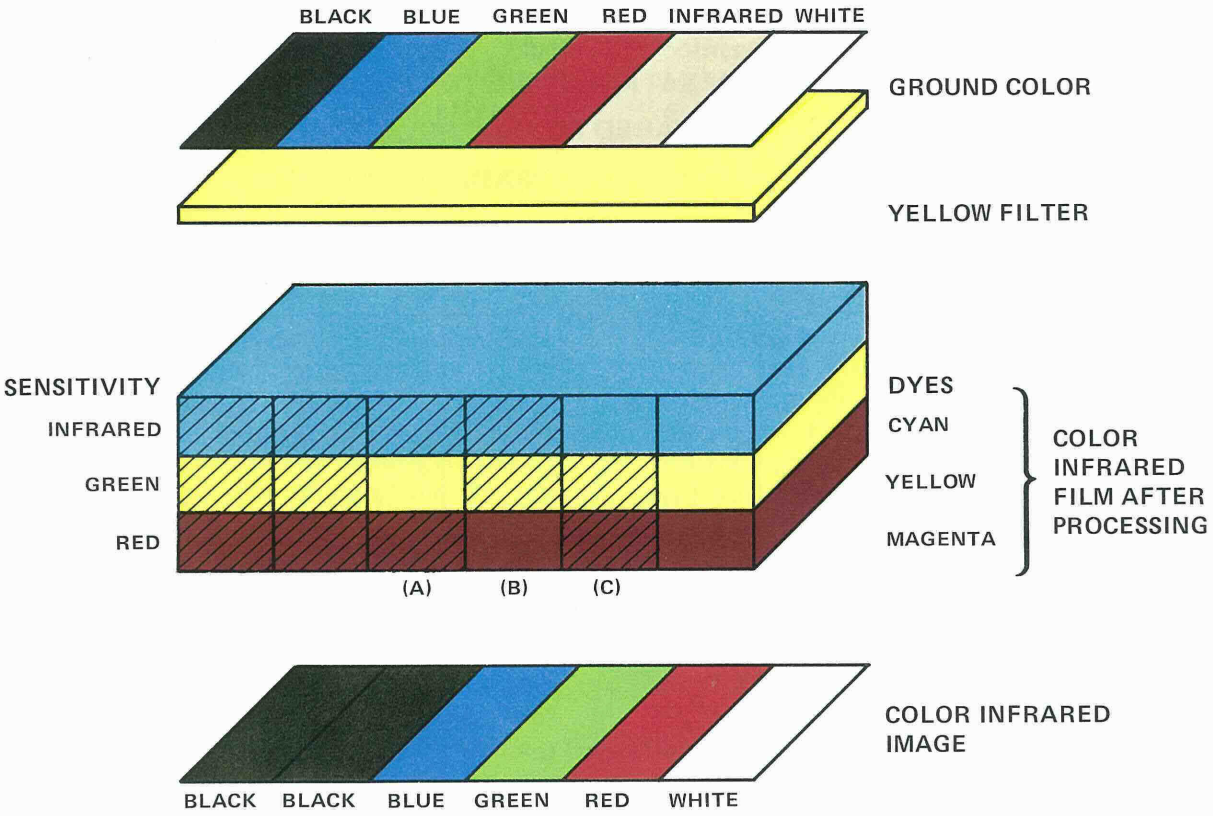

BLACK
BLUE
GREEN
RED
INFRARED
WHITE
GROUND COLOR
YELLOW FILTER
SENSITIVITY
INFRARED
GREEN
RED
DYES
CYAN
YELLOW
MAGENTA
COLOR INFRARED FILM AFTER PROCESSING
(A)
(B)
(C)
COLOR INFRARED IMAGE
BLACK
BLACK
BLUE
GREEN
RED
WHITE

Figure 9.- Reproduction of colors using color infrared reversal film.

subtractive color reversal film. The reversal process means that after the film is processed the amount of dye in each layer is inversely proportional to the exposure received.

The subtractive color process uses three absorption filters to control the transmission of red, green, and blue wavelengths. The filters used are cyan, which filters out red; magenta, which filters out green; and yellow, which filters out blue. When white light is passed through various densities and combinations of the three filters, essentially all colors can be produced. Applying the cross section of the color infrared film (fig. 9) as an example: When white light shines through the magenta and cyan dyes, the observed color is blue (point A); cyan and yellow dyes combine to produce green (point B); and magenta and yellow dyes produce red (point C).

When the color infrared transparency is viewed with white light, healthy vegetation is imaged as red. (See table 1.) This color results because healthy vegetation has a low reflectance in the green and red wavelengths and a high reflectance in the infrared wavelength. This, in turn after processing, causes the film to have no dye in the cyan layer and concentrations of dye in the magenta and yellow layers. When vegetation dies or is under stress, it loses infrared reflectance, which causes more of the cyan dye and less of the yellow and magenta dyes to show (ref. 9). Thus, the color of stressed vegetation shifts from red to yellow to green.

TABLE 1. – INTERPRETATION GUIDE TO COLOR PATTERNS ON COLOR INFRARED FILM AS RELATED TO FOREST INSECT DAMAGE

[From reference 8]

Object	Color	
	In nature or on color photographs	On color infrared photographs
Grass, meadows	Light green	Pink
Healthy deciduous foliage	Medium green	Pink, red
Healthy coniferous foliage	Dark green	Red-brown, red-violet
Dying trees	Yellow to red	Blue, pale yellow, white
Dead trees with small amount of foliage remaining	Gray	Blue-green
Defoliation or old mortality of all or a portion of a tree	Gray	Blue-green, gray

Aerochrome high-definition infrared (SO-131) film is normally used for high-altitude panoramic photography. This film, specifically designed for high-altitude reconnaissance, has an effective aerial film speed of 6. The resolving power in lines per millimeter for a target object contrast (TOC) of 1000:1 is 160; for a TOC of 1.6:1, it is 50 lines per millimeter (ref. 10).

Photointerpretation Aids

The influence of panoramic distortion because of camera characteristics can be reduced by using equal-area grid overlays. Mathematical models and associated computer programs written by the U.S. Department of Agriculture (USDA) Forest Service Engineering Geometronics Group in Washington, D.C., were used to construct the grids (ref. 11). These programs simulate the panoramic geometric characteristics of the Itek KA-80A optical bar camera. The projective equations required to model panoramic photography closely follow the analysis provided in the Manual of Remote Sensing (ref. 6).

By using one of these programs, PANGRID (ref. 11), and specifying the grid cell size, grid scale, scan angle limits, and several labeling options, a user can create an image of an equal-area grid on the ground. Image registration marks which reference 8° scan angles are also provided. Modeling assumptions include: flat Earth approximation, vertical and stable altitude profile, and constant aircraft altitude. The PANGRID program outputs a tape suitable for offline plotting on a California Computer Products (Calcomp) drum plotter. The software resides at the USDA Computer Center in Fort Collins, Colorado (ref. 11).

The equal-area grid overlay has proven to be a useful photointerpretation aid. The approximate size of small features can be estimated in proportion to the nearest grid interval. Distances can be determined by counting the number of grid intervals included between two points. This may require proportional estimating of partial grid intervals. Counting grid cells provides a relatively quick and accurate means of determining the size of the area. The nature of the grid itself supports the systematic recording and extraction of photo-observables on a cell-by-cell basis over a large project area; e.g., the number of dead and/or dying trees per cell.

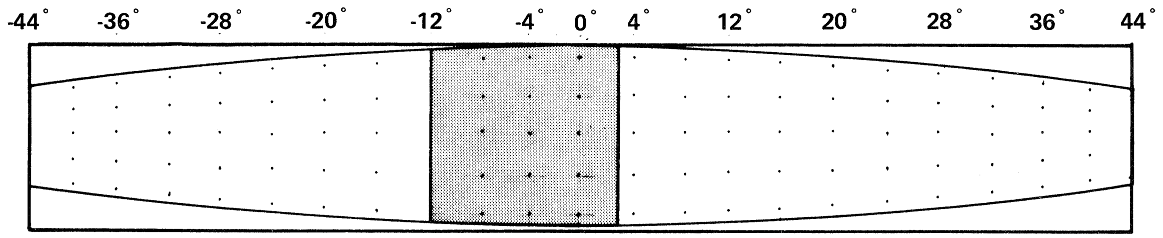
An example of an equal-area grid used for a mountain pine beetle survey is shown in figure 10. The grid has the following characteristics:

- Nadir scale - 1:30,000
- Cell size - 160 acres
- Rows of cells - 4
- Cells per row - 37 (40° to either side of nadir)
- Total cells per frame - 14.8
- Subcells per cell - 32 (5-acre cells)

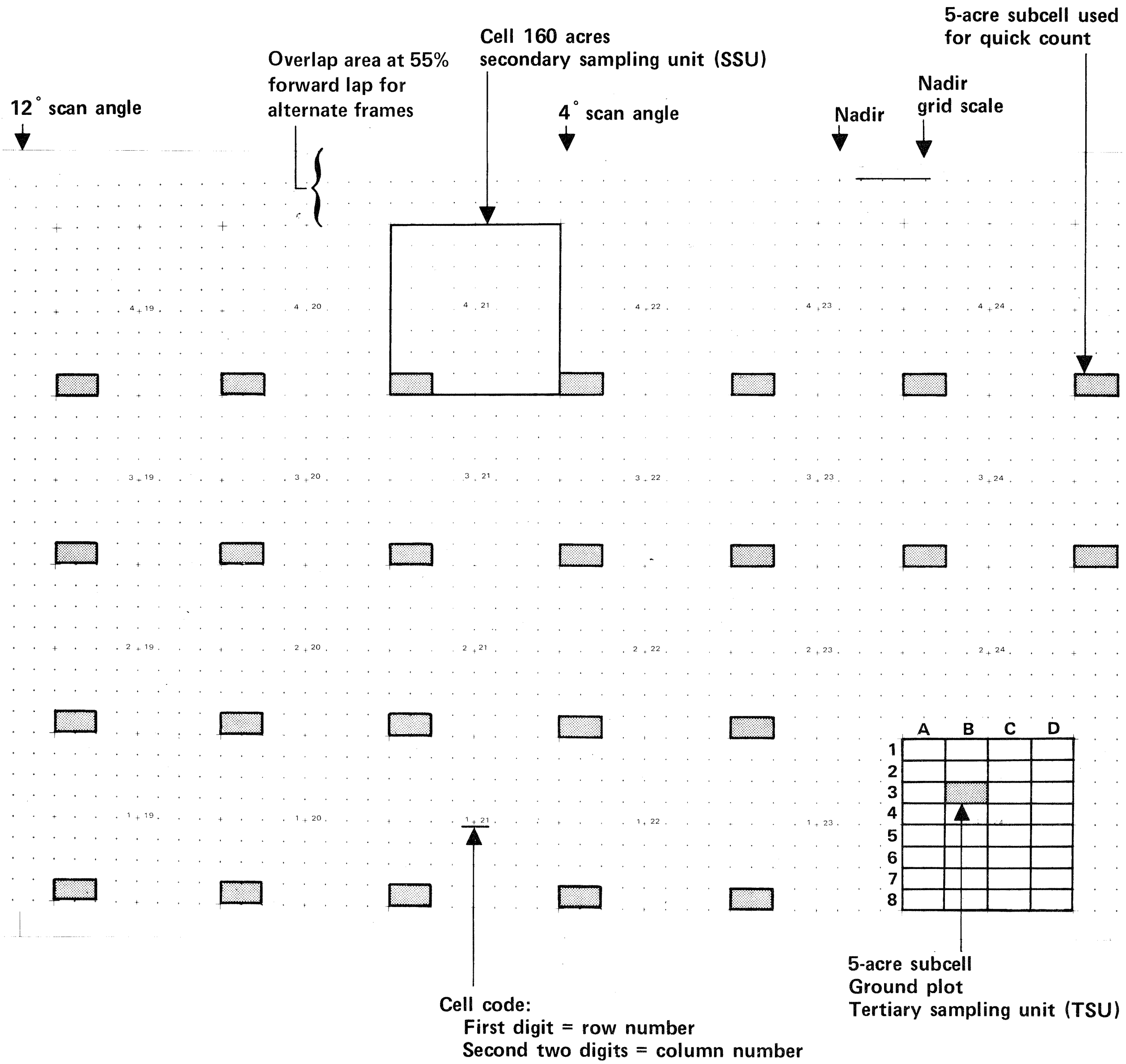
Two subcells per frame are included to allow for a 10-percent overlap for each alternate frame of photography. This assumes a 55-percent overlap between adjacent frames. If the film overlap is incorrect because of a system malfunction or an excessive variation in the terrain, gaps in the ground coverage can occur when the grids are used. Actual characteristics of the grids may vary because of the survey design and the sampling strategy.

Viewing Equipment

Camera systems employed in high-altitude photography normally use transparency film for maximum resolution; therefore, light tables are required for viewing the film indoors. A color-balanced 3800° Kelvin light source such as the Richards MIM-4 light table is best for this purpose. This table provides motor-driven film drives, a movable mount for the Bausch & Loom zoom stereoscopes, and an 11- by 39-inch working surface area (fig. 11).


-44°
-36°
-28°
-20°
-12°
-4°
0°
4°
12°
20°
28°
36°
44°

Entire grid


12° scan angle
Overlap area at 55% forward lap for alternate frames
Cell 160 acres secondary sampling unit (SSU)
4° scan angle
Nadir
Nadir grid scale
5-acre subcell used for quick count
4,19
4,20
4,21
4,22
4,23
4,24
3,19
3,20
3,21
3,22
3,23
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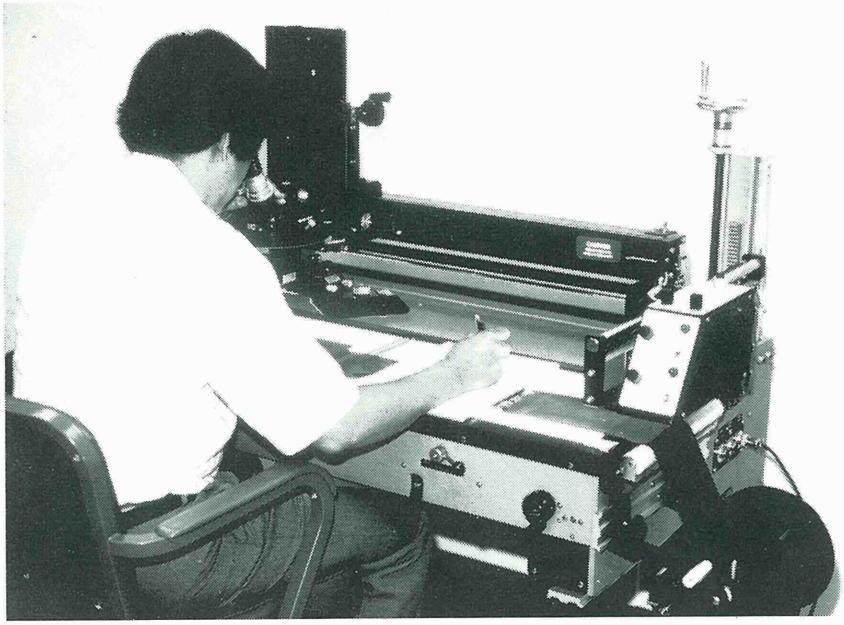
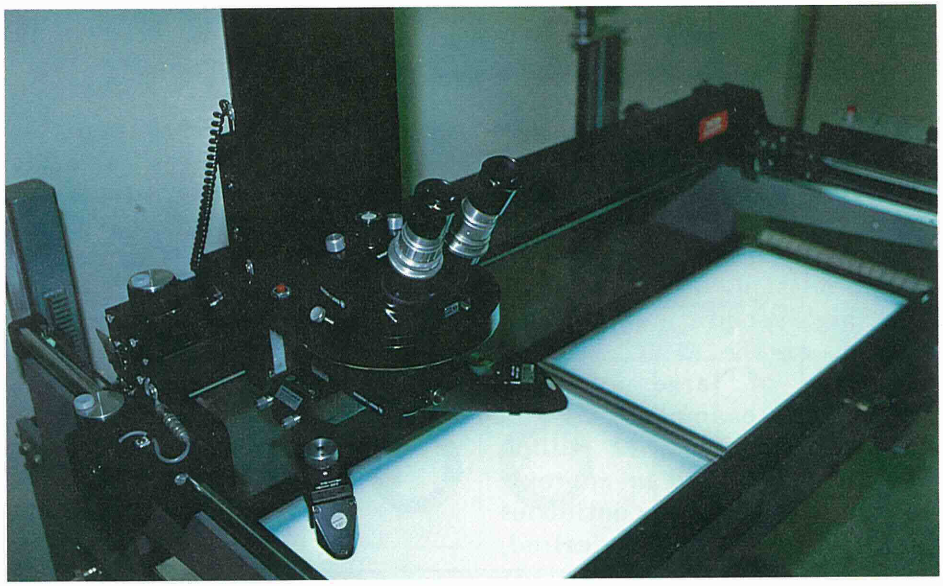
1
2
3
4
5
6
7
8
5-acre subcell
Ground plot
Tertiary sampling unit (TSU)
Cell code:
First digit = row number
Second two digits = column number

Figure 10.- Example of the central portion of an equal-area grid which can be used in the photointerpretation of each frame of photography.



(a) Richards MIM-4 light table.



(b) Bausch & Lomb zoom 240 stereoscopic viewing head.

Figure 11.- Laboratory equipment utilized in photointerpretation.

The Bausch & Loom zoom 240 stereoscope is a high-quality instrument which provides variable magnification up to 30x, monoscopic viewing, 360° optical rotation of the image, and independent focus on each eyepiece. It is easily mounted on the MIM-4 light table.

The film transparencies can also be interpreted in the field using one of several field-viewing instruments. These field viewers (fig. 12) have capabilities for stereoscopic viewing of either full-frame photographs or chips at 2x, 4x, or 7x magnification.

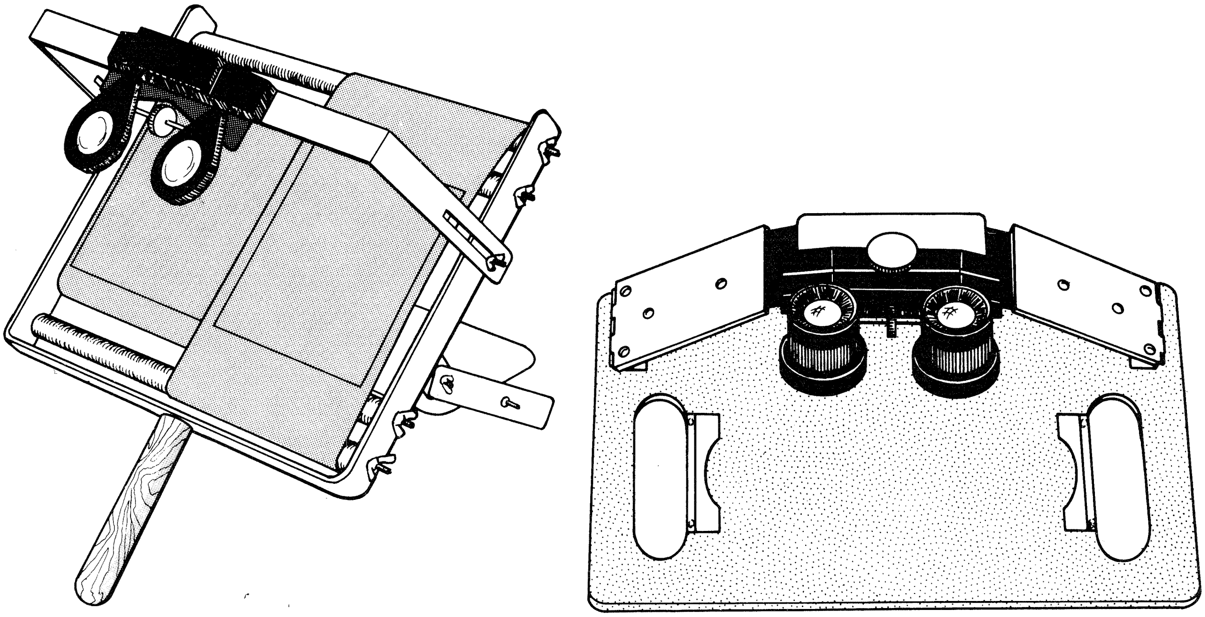
Advantages and Disadvantages

High-altitude high-resolution panoramic photography can provide the following advantages (ref. 12):

- The combination of high-resolution imagery and large-area coverage inherent in panoramic photography provides the opportunity for 100-percent photographic coverage of areas in which outbreaks of disease or insect pest infestation occur. This permits the extraction of two stages of data from one set of photographs, as opposed to conducting a sketch map survey followed by a photographic mission.
- Use of a high-speed, high-altitude aircraft such as the U-2C permits rapid coverage of large areas of forest land. For example, during a 1980 survey of Colorado, 12 million acres were photographed in approximately 4 hours (ref. 1). If continuous coverage of large areas is desired, rapid photographic acquisition is essential in order to accurately monitor vegetation damage, which is in an almost continuous state of change.
- Continuous coverage of forested areas provides the opportunity for photographs acquired for vegetation damage assessment to be used in other disciplines such as land use planning, watershed evaluation, road location, or timber sale planning. Therefore, an opportunity exists to share the cost of photographic acquisition with other resource management specialists.

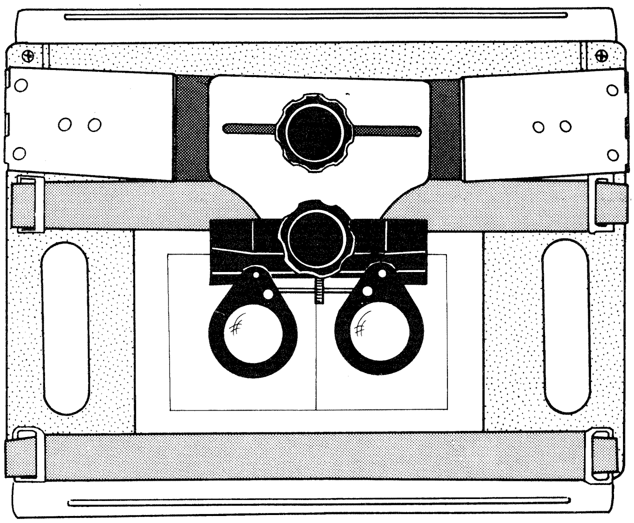
Potential disadvantages of panoramic photography in forest pest management include:

- The unusual film format (4.5 by 50 inches) is cumbersome to handle in both the office and the field. In addition, the continuously changing photographic scale requires special photointerpretation aids for extracting data on areas of infestation or for classifying damage intensity on grids of equal land area. Also, photointerpretation accuracy tends to decrease as the obliquity increases beyond about 35°.
- The Itek KA-80A (optical bar) panoramic camera is currently used in high-altitude aircraft. Presently, no civilian aircraft is capable of accommodating this camera in an efficient manner; thus, photography can be acquired only through NASA. Photographic acquisition, therefore, is dependent on the workload of NASA and the availability of a limited number of aircraft.
- Photographic acquisition with the Itek KA-80A panoramic camera can be expensive when compared to conventional methods for photographic coverage.



(a) Klein full-frame viewer.

(b) Johnson chip viewer.



(c) Johnson full-frame viewer.

Figure 12.- Three viewers for interpreting 5-inch-wide panoramic transparencies in the field.

PHOTOINTERPRETATION

The photointerpreter involved in mountain pine beetle surveys is required to classify only one feature; i.e., trees killed in the previous year by the beetle. This classification process requires, however, that many photographic features be analyzed and rejected as not being characteristic faders.

This section provides the photointerpreter with the photographic characteristics of typical types of western vegetation, trees killed by the mountain pine beetle, and other types of insect damage. Examples of features which can be easily misidentified are also included. Stereoscopic photographs which illustrate the many features have been enlarged to a scale of about 1:7000 from the original nadir photographic scale of 1:30,000. The photointerpretation is normally conducted using color infrared transparencies and magnifications of 8x to 14x. Printed copies of the original small-scale photographs lose too much resolution because of the various steps in the printing process; therefore, photographic enlargements are used for illustrations. When viewed with normally available 2x or 4x stereoscopes, these enlargements approximate what is seen on the original transparencies.

The identification of a feature on the photography is based on an analysis of one or more of the following characteristics: shape, size, color or tone, pattern, shadow, location, and texture. Stereoscopic viewing also adds the important dimension of height.

The vegetation types in the Western United States are stratified by elevation. Therefore, the elevation of a site is another important characteristic for identifying a feature on the photography. The most important characteristics for identification are color, shape, and elevational location; shadow is very useful, but the trees must be in open stands. The change in vegetation with altitude is illustrated in figures 13 and 14, using southern Colorado as an example. Color transparencies have more resolution and color definition than can be reproduced in print; but shapes, shadows, and textures are apparent. The general photographic characteristics of some of the major forest types in the Western United States are illustrated in table 2.

Host Species

Ponderosa pine and lodgepole pine are the primary hosts attacked by the mountain pine beetle. On color infrared film, current-year faders (dead for 1 year) are distinguished from healthy trees by their yellow color and somewhat thinner crowns. The crowns of faders dead for 2 years are blue to gray in color with considerable needle loss.

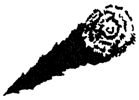
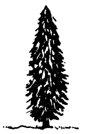
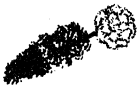
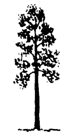
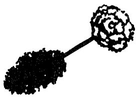
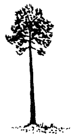
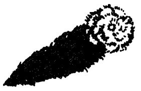
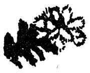
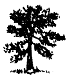
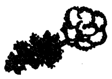
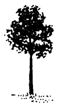
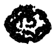
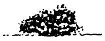
Three ages of ponderosa pine faders in Colorado are shown in the low oblique photograph given in figure 15, as well as in the aerial photograph and corresponding ground photographs given in figures 16 and 17. Ponderosa pine faders in the Black Hills National Forest, South Dakota, and lodgepole pine faders in the Shoshone National Forest, Wyoming, are shown in figures 18 and 19, respectively. These faders can be compared with the surrounding healthy trees which are dark red.

Two stand types of lodgepole pine faders in the Gallatin National Forest, Montana, are shown in figure 20. Again, the current-year faders and healthy vegetation should be compared.

Sources of Error

Photointerpretation, which is verified by a ground examination, is subject to two types of error: (1) errors of commission, which occur when the photointerpreter identifies a feature on the photograph as a current-year fader and in reality it is not a fader, and (2) errors of omission, which occur when the photointerpreter does not identify a fader and in reality one is present. Errors of commission are the ones for which the most information is available.

TABLE 2. – GENERAL PHOTOGRAPHIC CHARACTERISTICS FOR THE MAJOR WESTERN FOREST TYPES

Cover type	Elevation range, ft	Crown shape[a]		Relative color[b]	Stand texture	Growth characteristics
		Vertical and shadow	Side view			
Spruce/fir	2000 to 11,500			Dark red to purple	Medium (dense stands usually uneven aged)	Subalpine zone to timberline on cool, moist sites
Lodgepole pine	0 to 11,000			Dark red	Fine (dense stands usually even aged)	Coastal varieties: 0 to 2000 ft elevation range; inland varieties: 1500 to 3000 ft elevation range in north and 7000 to 11,500 ft in south
Ponderosa pine	0 to 9500			Red	Medium to coarse (stands usually grown in open areas)	Southern slopes on dry sites
Douglas-fir, true fir	2000 to 9000			Dark red	Medium (stands can be dense, often even aged)	Douglas-fir: northern slopes on moist sites
Pinyon/ Juniper	5000 to 7500			Very dark red	Medium to coarse (stands grown in open areas, similar to ponderosa pine but with a much shorter shadow)	Dry sites
Aspen	0 to 11,000			Bright red to pink	Fine to medium (even-aged stands)	Moist sites, usually below the spruce/ fir type
Oakbrush	5500 to 7000			Bright red to pink	Fine (very short)	On dry sites

[a] Crowns are drawn in proportion to each other.

[b] Colors are relative to each other and are not absolute; film colors will vary, depending on exposure and processing.

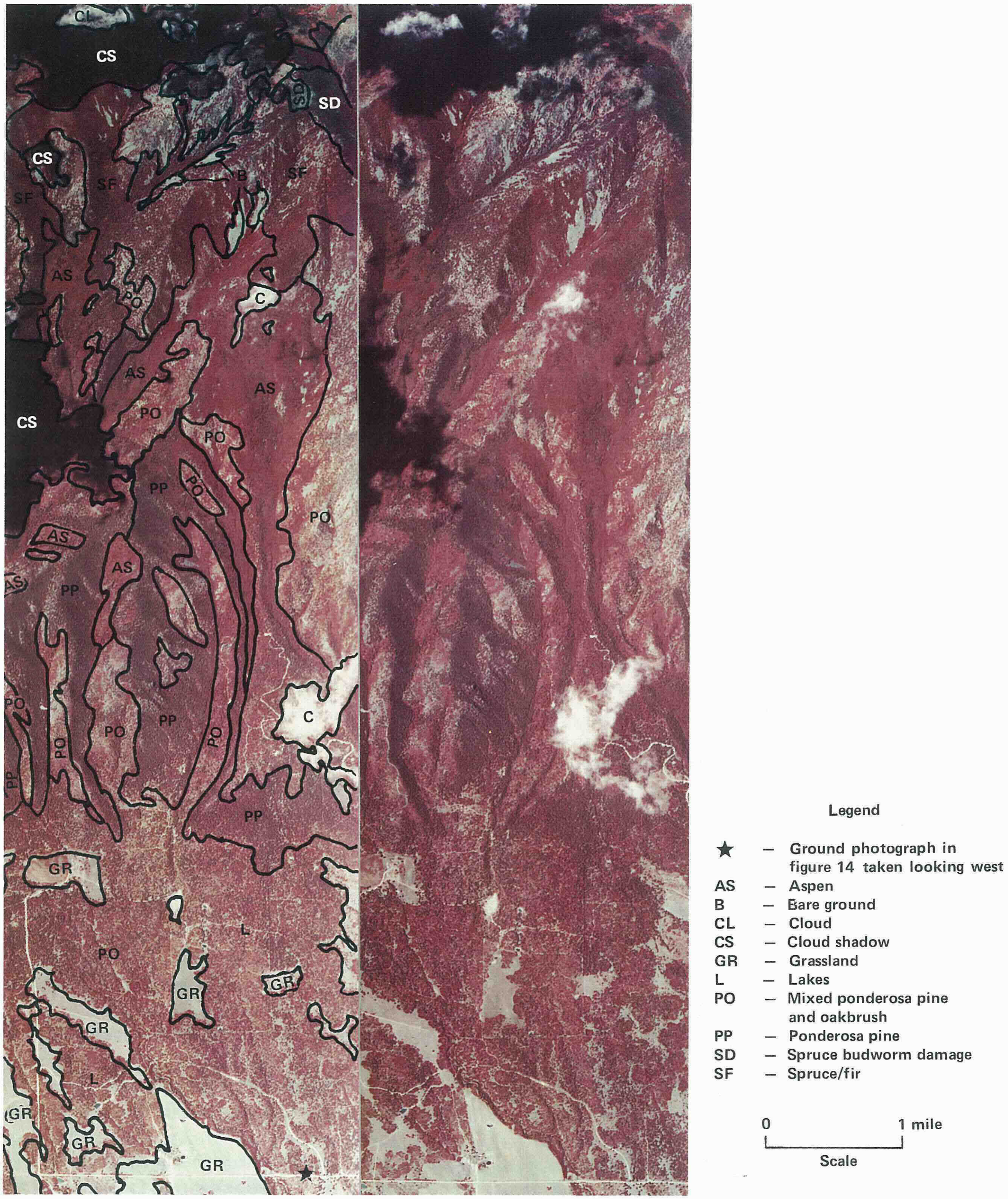

CL
CS
SD
SD
CS
SF
SF
B
SF
AS
PO
C
AS
AS
PO
PO
CS
PO
PP
PO
PO
AS
AS
PP
AS
PO
PO
PO
PP
PO
C
PP
PP
GR
L
PO
GR
GR
GR
L
GR
GR
GR
★
Legend
★ – Ground photograph in figure 14 taken looking west
AS – Aspen
B – Bare ground
CL – Cloud
CS – Cloud shadow
GR – Grassland
L – Lakes
PO – Mixed ponderosa pine and oakbrush
PP – Ponderosa pine
SD – Spruce budworm damage
SF – Spruce/fir
0
1 mile
Scale

Figure 13.- Stereoscopic pair showing major vegetation types in the Front Range of Colorado (NASA Mission 80-122 on August 22, 1980; frames 51 and 52 reproduced at the original scale).

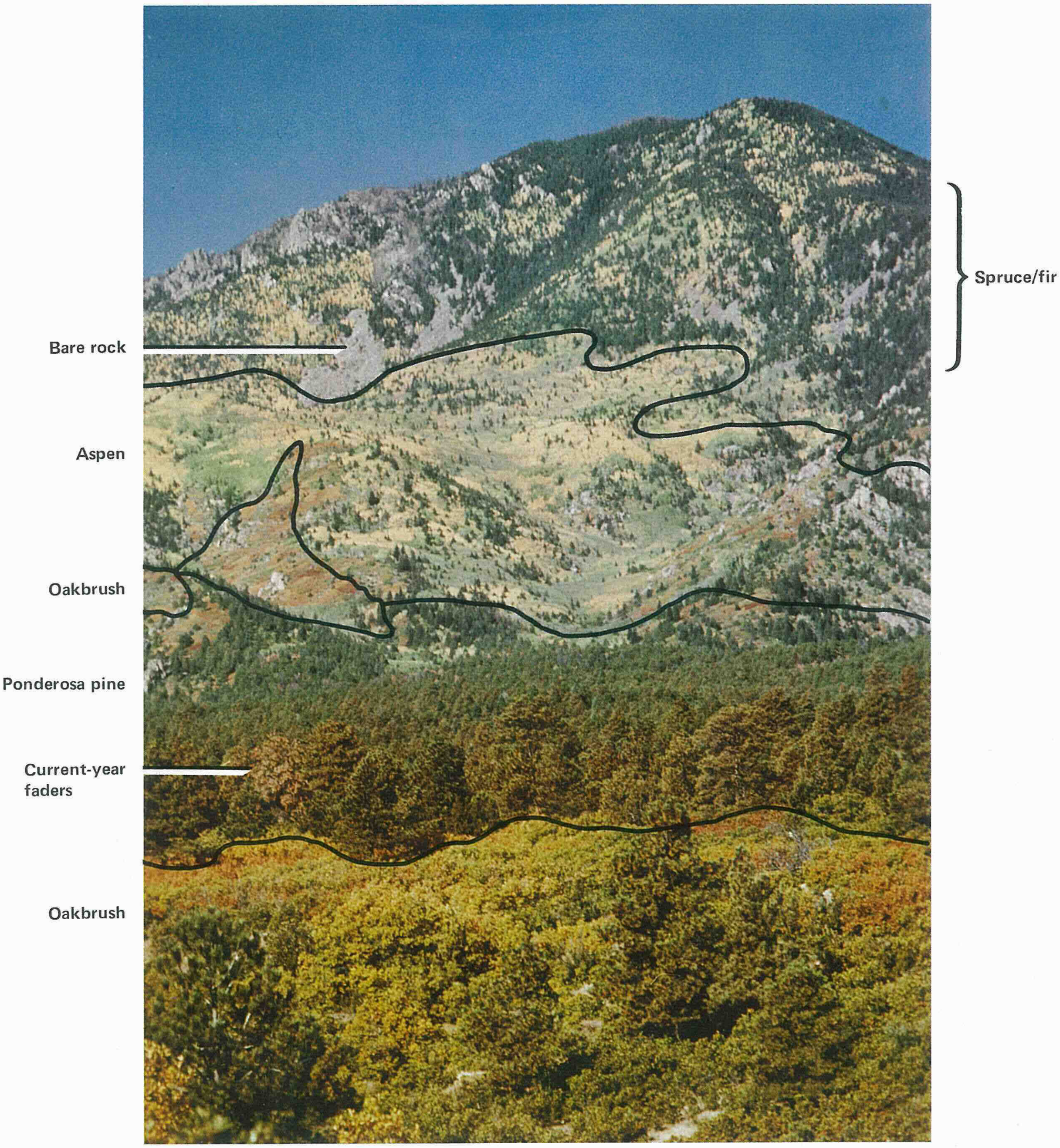

Spruce/fir
Bare rock
Aspen
Oakbrush
Ponderosa pine
Current-year faders
Oakbrush

Figure 14.- Ground photograph showing major vegetation types in the Front Range of Colorado. Area coverage is similar to that in figure 13. The photograph, in which fall coloration of aspen is evident, was taken October 1980.

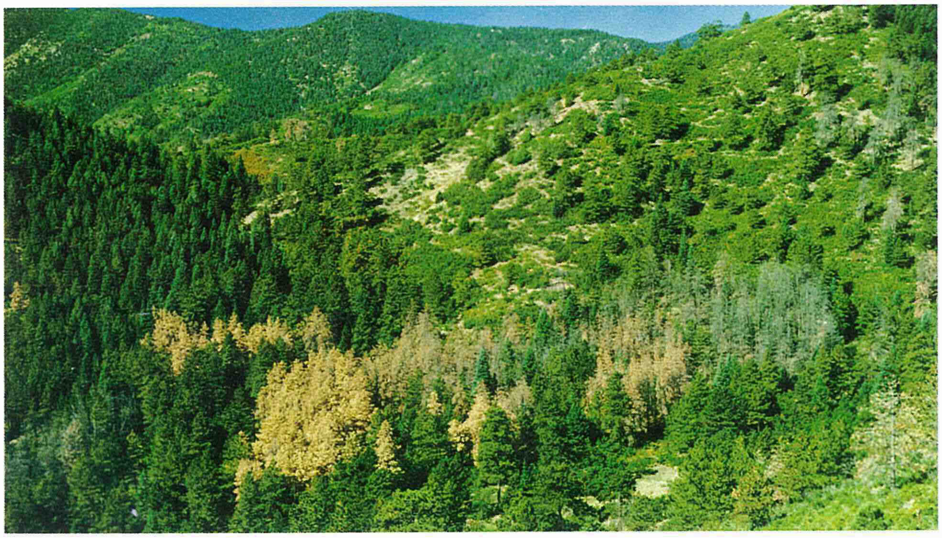


Figure 15.- Low oblique photograph showing three ages of ponderosa pine killed by the mountain pine beetle in Colorado.

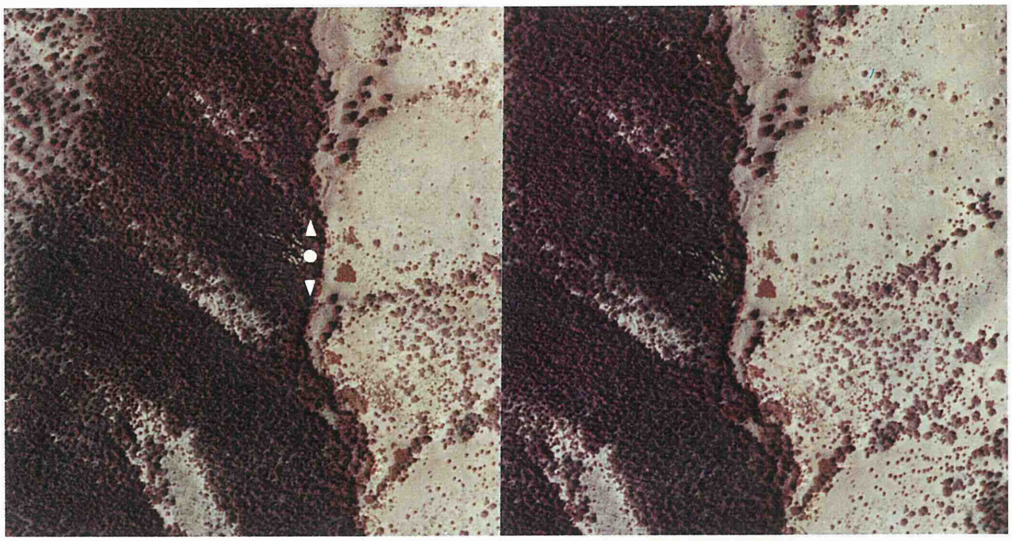
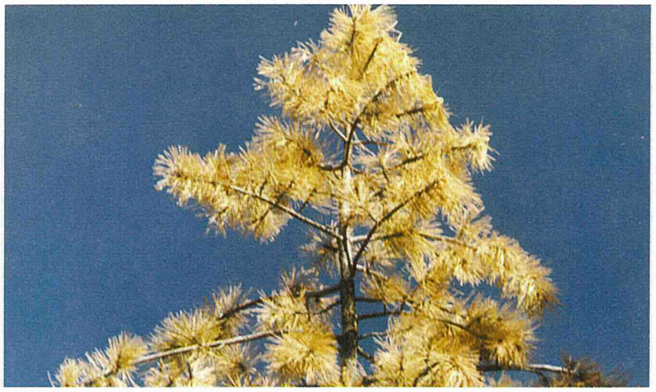
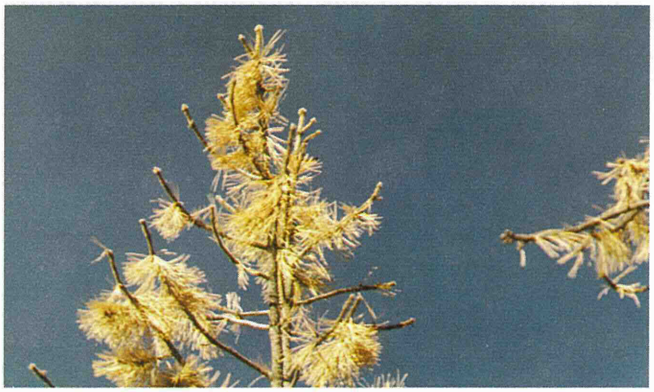


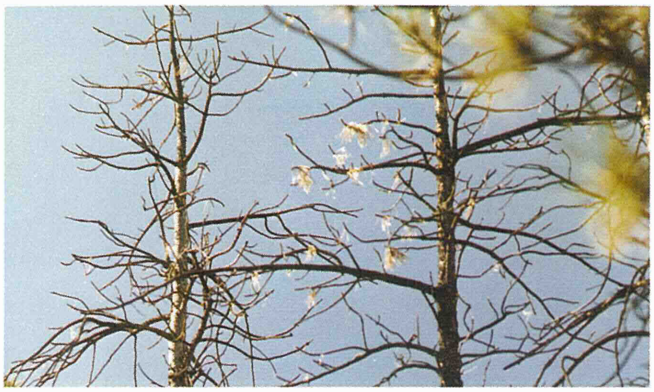
Figure 16.- High-altitude panoramic photography showing three ages of ponderosa pine faders in the Front Range of Colorado (NASA Mission 80-122 on August 22, 1980; frames 1154 and 1155; scale: ≈1:7500). The symbols ▲, ●, and ▼ correspond to figures 17a, 17b, and 17c, respectively.



(a) Current-year fader (dead for 1 year).

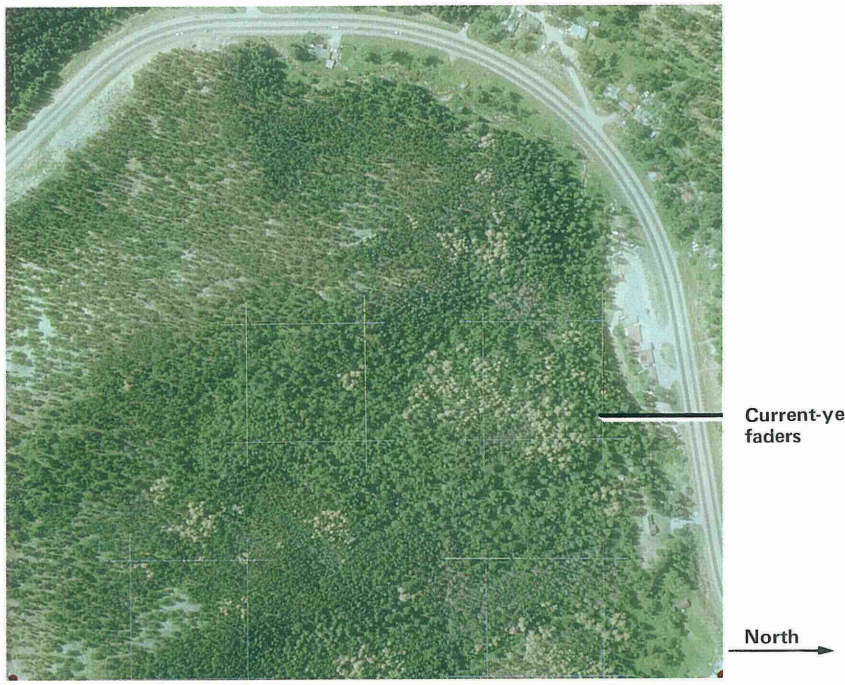


(b) 1-year-old fader (dead for 2 years).

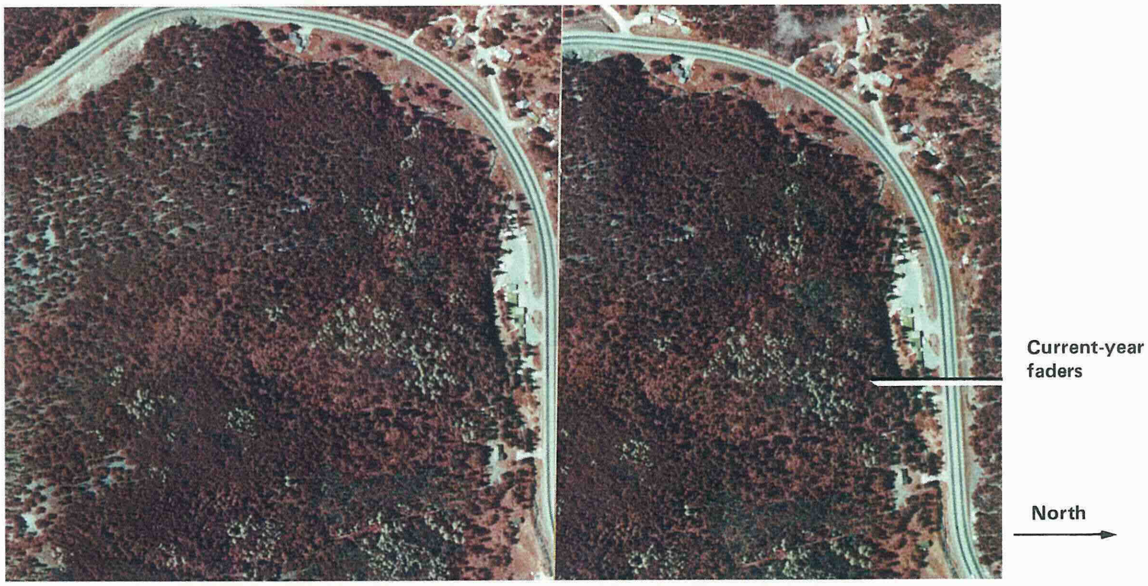


(c) Old kill.

Figure 17.- Close-up ground photographs showing three ages of ponderosa pine killed trees in the Front Range of Colorado. The photographs, which correspond to figure 16, were taken October 1980.

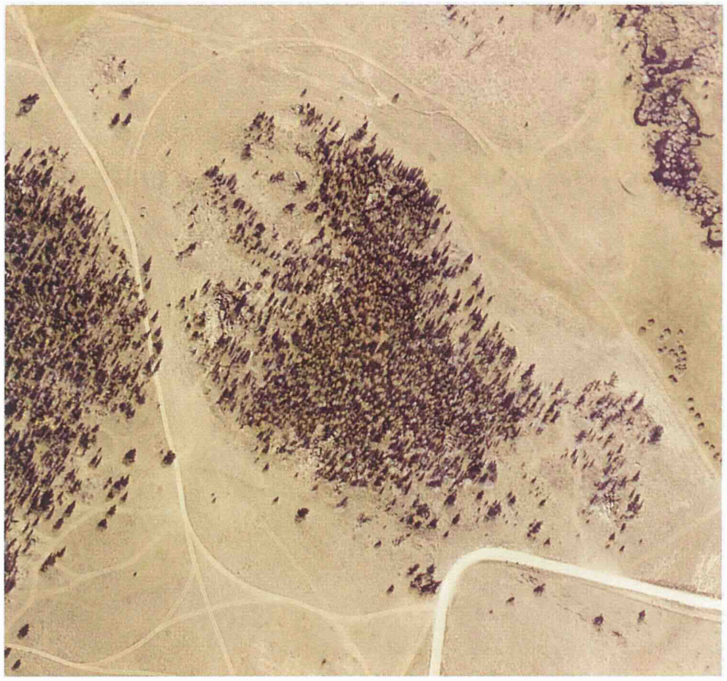

Current-year faders
North

(a) Normal color photograph of mountain pine beetle infestation (Plot 31-4-2, summer 1978, scale: ≈1:6000).

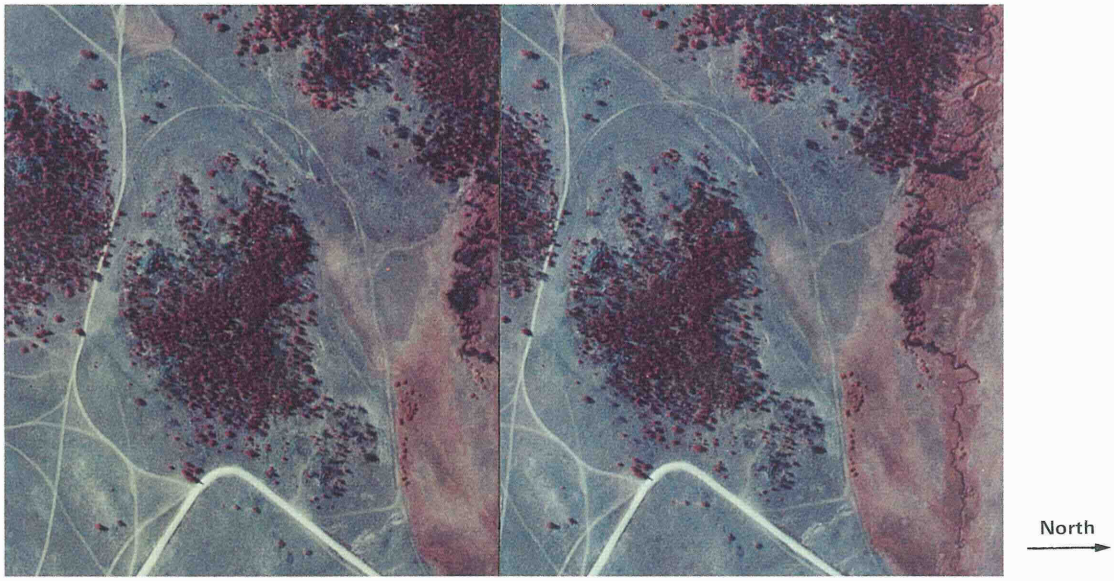

Current-year faders
North

(b) Color infrared high-altitude panoramic photography (NASA Mission 78-116 on August 24, 1978; frames 59 and 60; scale: ≈1:7500).

Figure 18.- Aerial photographs showing ponderosa pine faders in the Black Hills National Forest, South Dakota, taken with two camera systems.

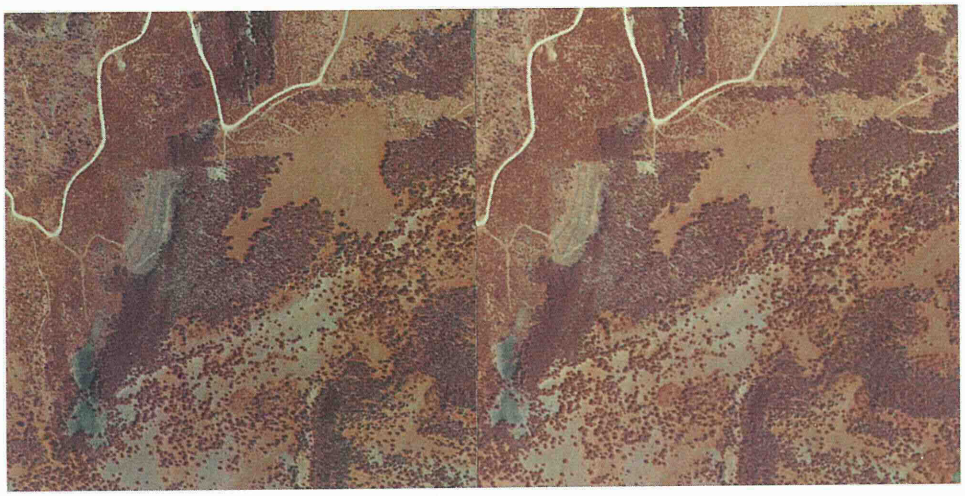


(a) Normal color photograph of mountain pine beetle infestation (Plot 308; August 20, 1981; scale: ≈1:6000).

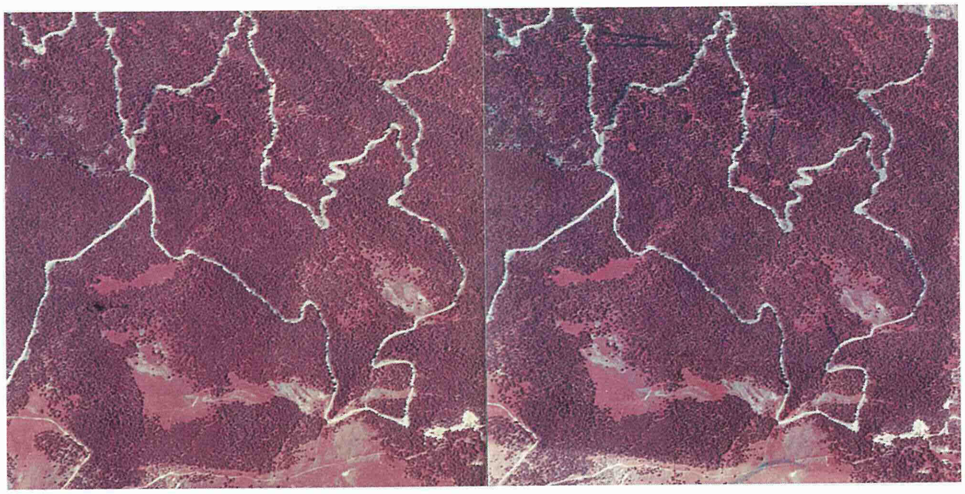


(b) Color infrared high-altitude panoramic photography (NASA Mission 81-177 on September 17, 1981; frames 496 and 497; scale: ≈1:7500).

Figure 19.- Aerial photographs showing lodgepole pine faders in the Shoshone National Forest, Wyoming, taken with two camera systems.



(a) Open stand.



(b) Dense stand.

Figure 20.- High-altitude panoramic photography showing lodgepole pine faders in the Gallatin National Forest, Montana (NASA Mission 78-104 on July 25, 1978; scale: ≈1:7500).

Commission Errors

In two previous studies using panoramic photography, experienced photointerpreters made several types of misidentification. The photointerpreters selected plots on the photography which were to contain current-year ponderosa pine faders. Ground examination proved this interpretation to be incorrect.

Several factors confound the process of identifying current-year faders on the aerial photography. For example:

- The progress of tree fading and related color changes varies from year to year and between sites, depending primarily on yearly site-specific moisture regimens.
- Trees exposed to various environmental factors (e.g., high winds, heavy snowfall, and hail) can have their needles prematurely removed, making current-year faders appear as old kill.
- Dead trees of other species (e.g., Douglas-fir, Engelmann spruce, and white fir) have been identified as current-year faders.
- In some instances, insect defoliation of a single tree (e.g., western spruce budworm defoliation of Douglas-fir) can be confused as a current-year fader.
- Under certain lighting conditions with monoscopic viewing, physical features such as rocks and openings within a stand can be confused with faders.

In general, most of these errors could have been avoided by following the strict criteria established for photographic characteristics of current-year faders and by stereoscopic viewing of the photography. The problem arises when trying to include current-year faders which may have a noncharacteristic appearance because of a special condition; i.e., early removal of needles by wind or hail.

Stereoscopic viewing is usually not possible at all stages in surveys which use high-altitude photography because of the large number of photographs involved and the increased photointerpretation time which it would require.

Figures 21, 22, 23, and 24 present examples of features which have been misidentified as trees killed by the mountain pine beetle.

Omission Errors

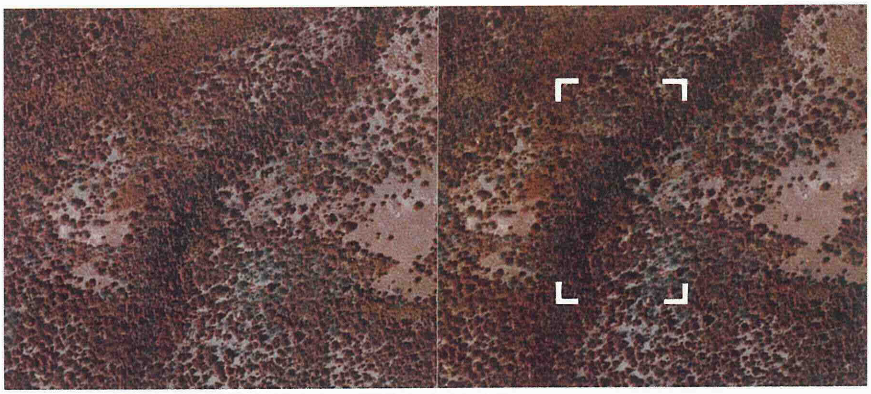
Many factors (e.g., stand density and structure, shadowing, and distance from nadir) prohibit an accurate count of current-year faders on the panoramic photography. Statistically, the omission error is not as significant as the commission error for large-area estimates. This is true as long as the photographic counts are consistent; i.e., all photographic counts are always under the actual ground counts by the same percentage.

In several previous studies using panoramic photography, a count of faders on the photography and a count of actual faders on the ground showed that the photographic counts were approximately one-half that of the ground counts. This ratio varies between studies and usually includes counts from nadir out to ±40° to either side of nadir.

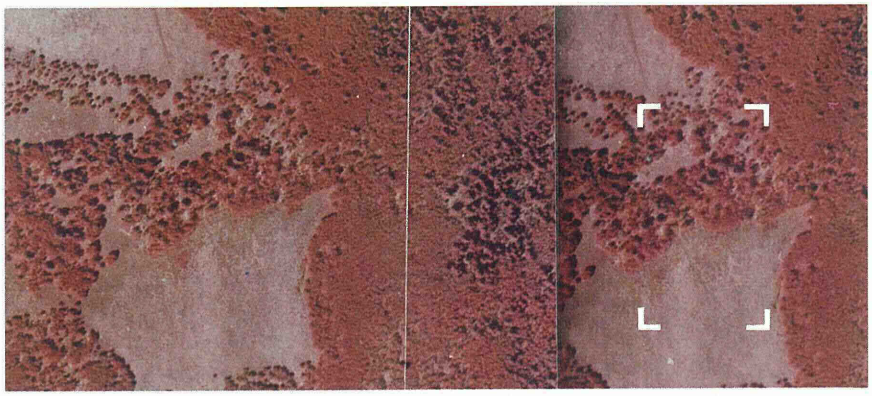
To analyze the effect of photointerpretation accuracy as a function of distance from nadir, two studies were conducted using data collected in Colorado. The data were separated into two groups: (1) all plots ±20° to either side of nadir and (2) all plots ±20° to ±40° to either side of nadir.

One study, which relied on monoscopic viewing of the photography, showed that the counts were statistically different between the two scan angle data groups. When stereoscopic viewing was used, there was no significant difference in photointerpretation accuracy as a function of distance from nadir (ref. 1). This was not the case, however, for the study in the Gallatin National Forest (ref. 3).

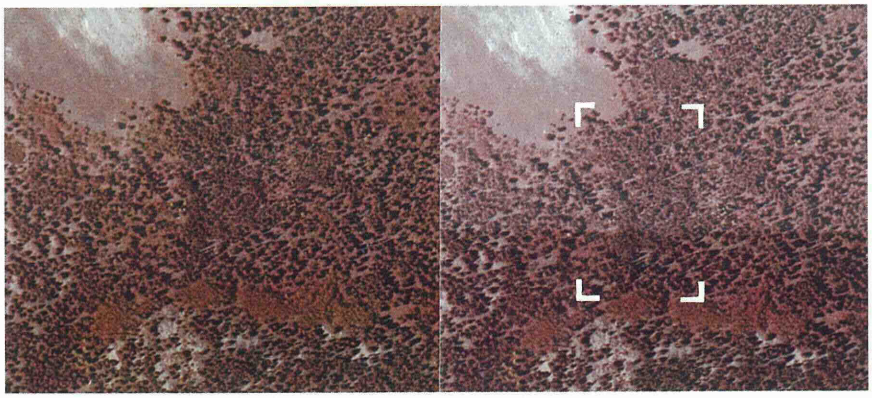
Appendix B contains additional photointerpreter exercises to be used for training.



(a) Lodgepole pine faders (frames 455 and 456).

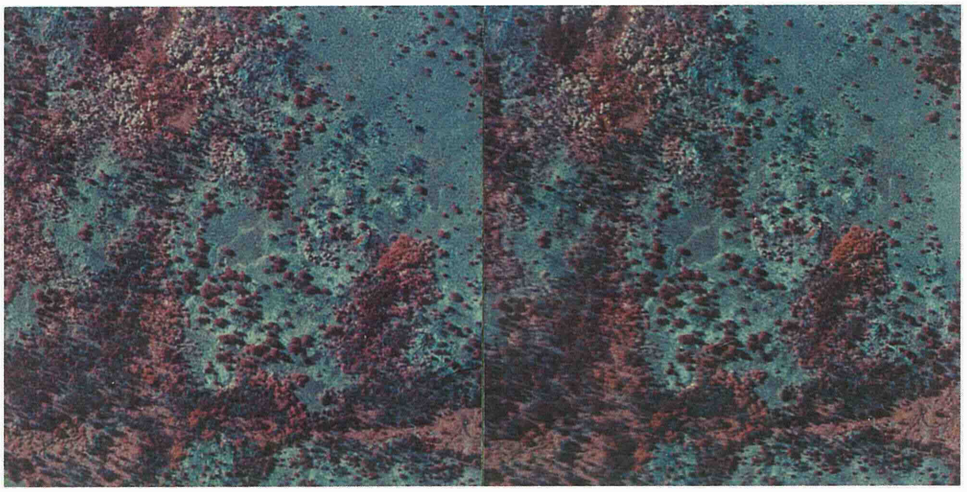


(b) Douglas-fir faders (frames 239 and 240).

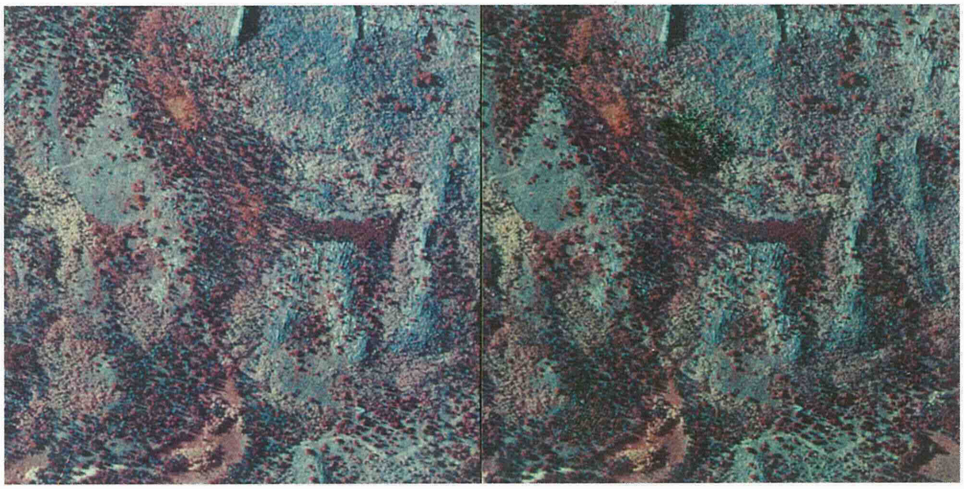


(c) Limber pine faders (frames 565 and 566).

Figure 21.- High-altitude panoramic photography showing faded trees of three timber types in Colorado misidentified as ponderosa pine faders (NASA Mission 80-121 on August 21, 1980; scale: ≈1:7500).

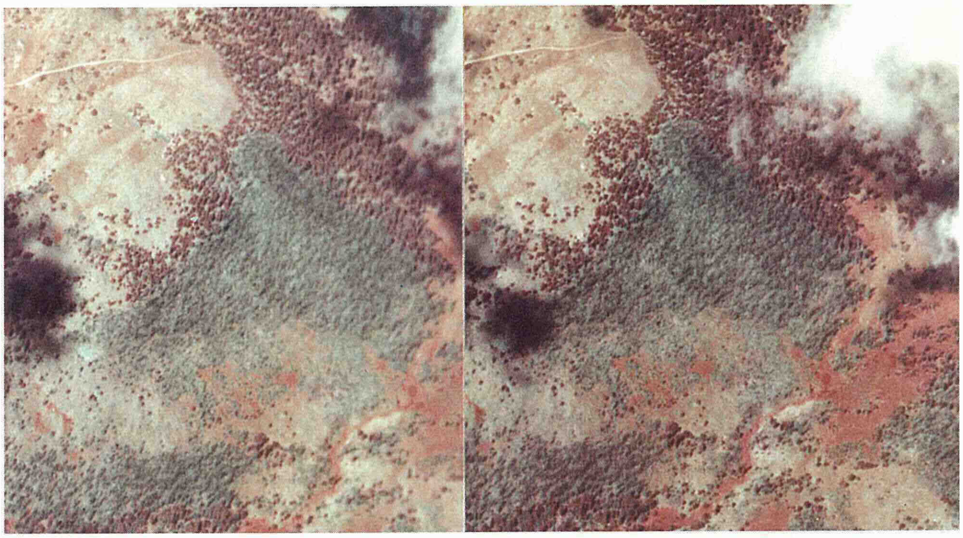


(a) Ground plot 306 (frames 495 and 496).

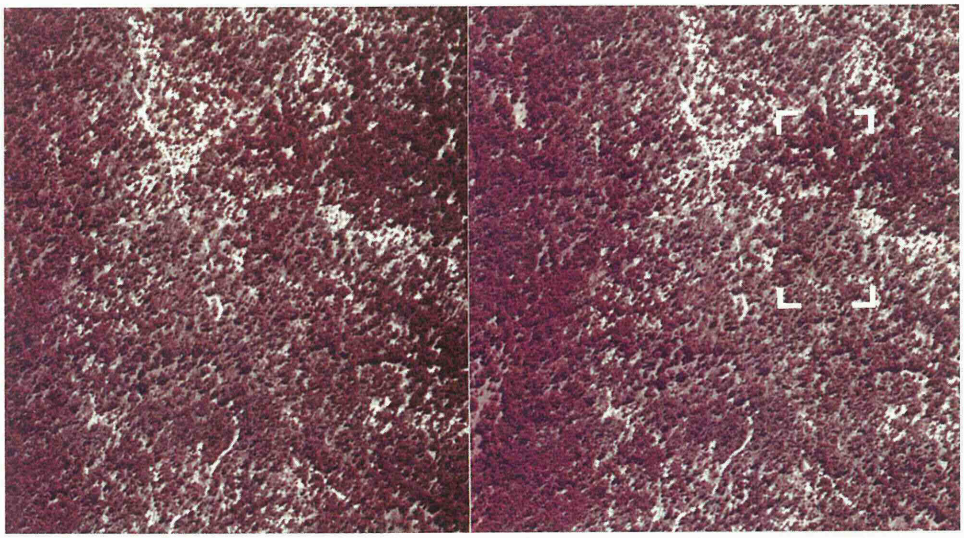


(b) Ground plot 307 (frames 496 and 497).

Figure 22.- High-altitude panoramic photography showing faded lodgepole pine and whitebark pine in Wyoming which may contribute to commission errors (NASA Mission 81-177 on September 17, 1981; scale: ≈1:7500).

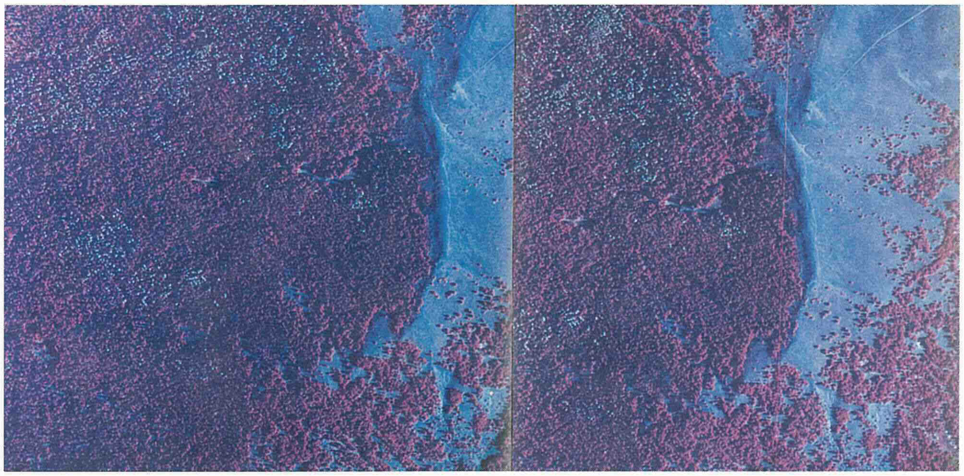


(a) Spruce budworm defoliation (frames 51 and 52, scale: ≈1:9000).

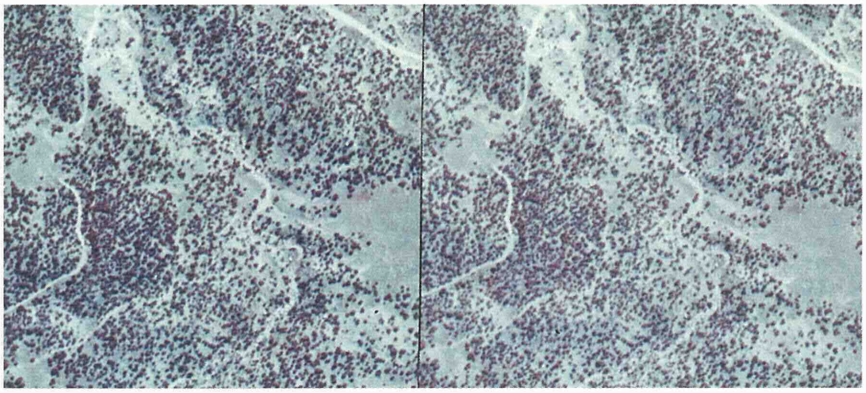


(b) Bare ground (frames 122 and 123, scale: ≈1:7500).

Figure 23.- High-altitude panoramic photography showing possible sources of commission errors (NASA Mission 80-122 on August 22, 1980).



(a) Fall coloration of larch in the Malheur National Forest, Oregon (NASA Mission 77-171 on October 18, 1977; scale: ≈1:7500).



(b) Pinyon and juniper in Colorado (NASA Mission 79-118 on August 7, 1979; frames 210 and 211; scale: ≈1:7500).

Figure 24.- High-altitude panoramic photography of other vegetation which may contribute to commission errors.

LOGIC

The information presented in the previous sections can best be used in interpreting aerial photography when organized in a logical analysis process. Figure 25 presents a deductive approach to analyzing color infrared imagery for counting current-year faders.

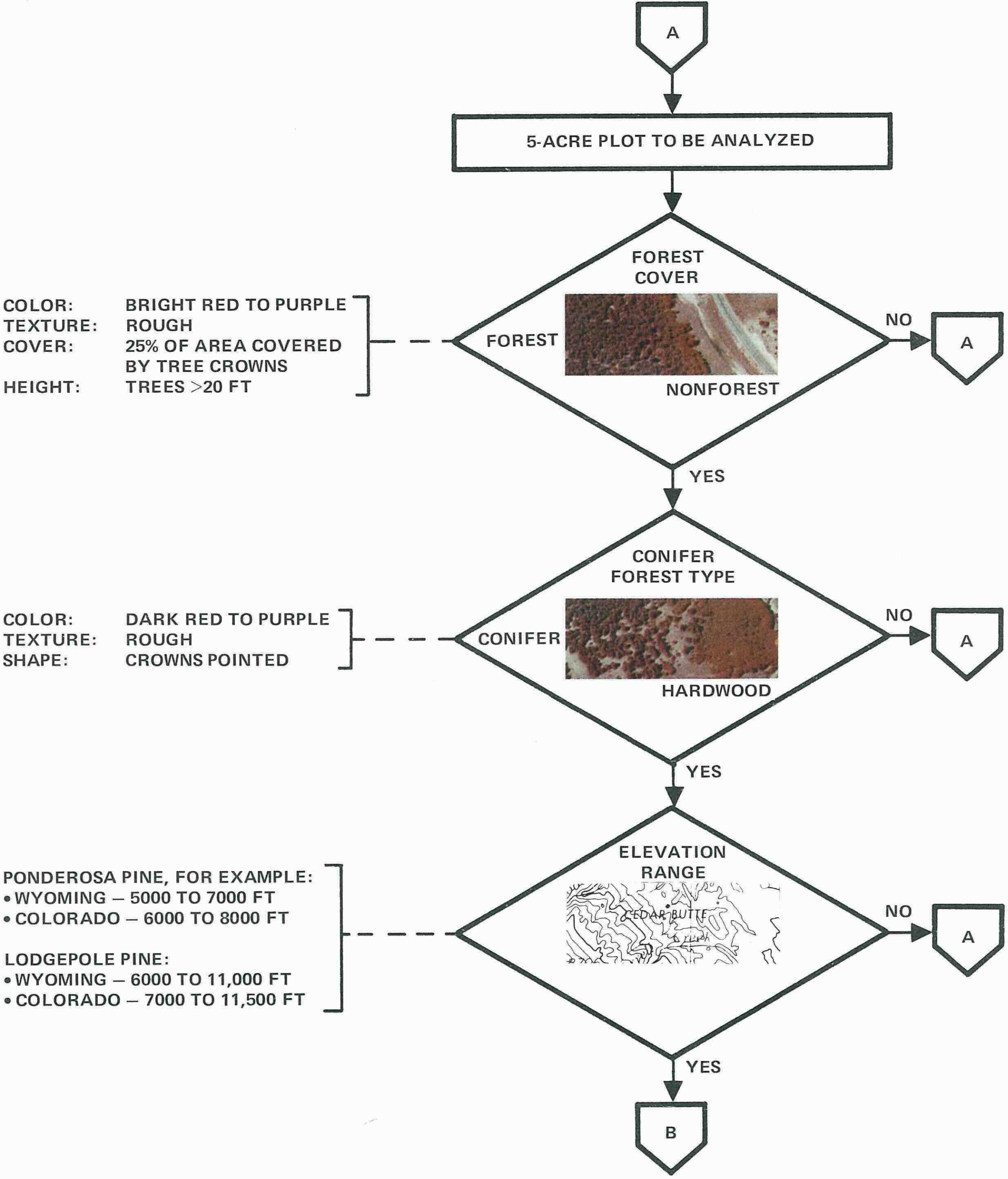

A
5-ACRE PLOT TO BE ANALYZED
COLOR: BRIGHT RED TO PURPLE
TEXTURE: ROUGH
COVER: 25% OF AREA COVERED BY TREE CROWNS
HEIGHT: TREES >20 FT
FOREST COVER
FOREST
NONFOREST
NO
A
YES
COLOR: DARK RED TO PURPLE
TEXTURE: ROUGH
SHAPE: CROWNS POINTED
CONIFER FOREST TYPE
CONIFER
HARDWOOD
NO
A
YES
PONDEROSA PINE, FOR EXAMPLE:
• WYOMING – 5000 TO 7000 FT
• COLORADO – 6000 TO 8000 FT
LODGEPOLE PINE:
• WYOMING – 6000 TO 11,000 FT
• COLORADO – 7000 TO 11,500 FT
ELEVATION RANGE
CEDAR BUTTE
NO
A
YES
B

Figure 25.- Decision logic for counting ponderosa pine or lodgepole pine killed by the mountain pine beetle.

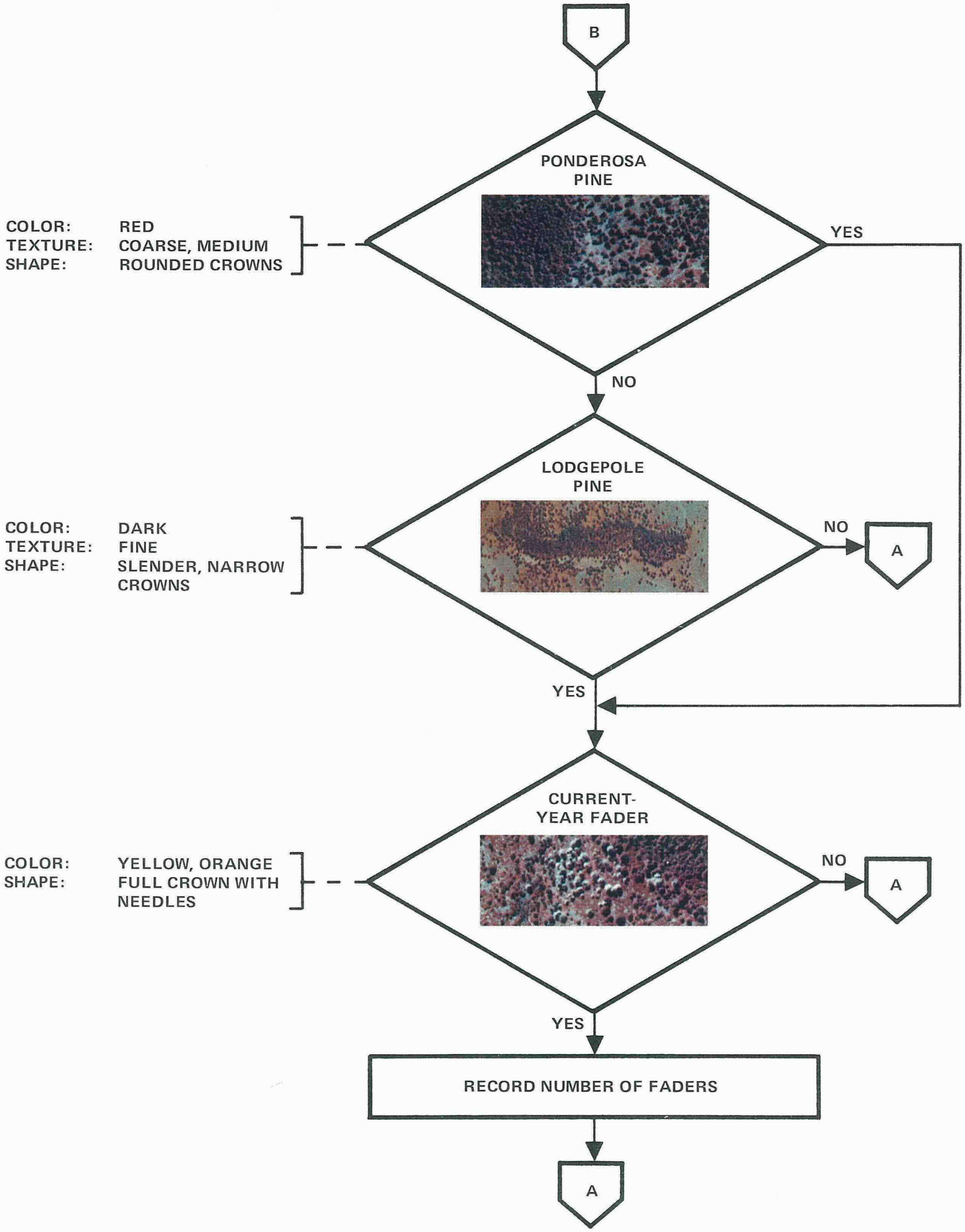

B
PONDEROSA PINE
COLOR: RED
TEXTURE: COARSE, MEDIUM
SHAPE: ROUNDED CROWNS
YES
NO
LODGEPOLE PINE
COLOR: DARK
TEXTURE: FINE
SHAPE: SLENDER, NARROW CROWNS
NO
A
YES
CURRENT-YEAR FADER
COLOR: YELLOW, ORANGE
SHAPE: FULL CROWN WITH NEEDLES
NO
A
YES
RECORD NUMBER OF FADERS
A

Figure 25.- Concluded.

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APPENDIX A

PHOTOGRAPHIC COVERAGE OF HIGH-ALTITUDE PANORAMIC CAMERA SYSTEMS

Figure A-1 shows the ground coverage and scan angle for the Itek KA-80A optical bar panoramic camera. The photographic scale versus scan angle and the forward and lateral coverage for high-altitude panoramic photography are illustrated in figures A-2 and A-3, respectively.

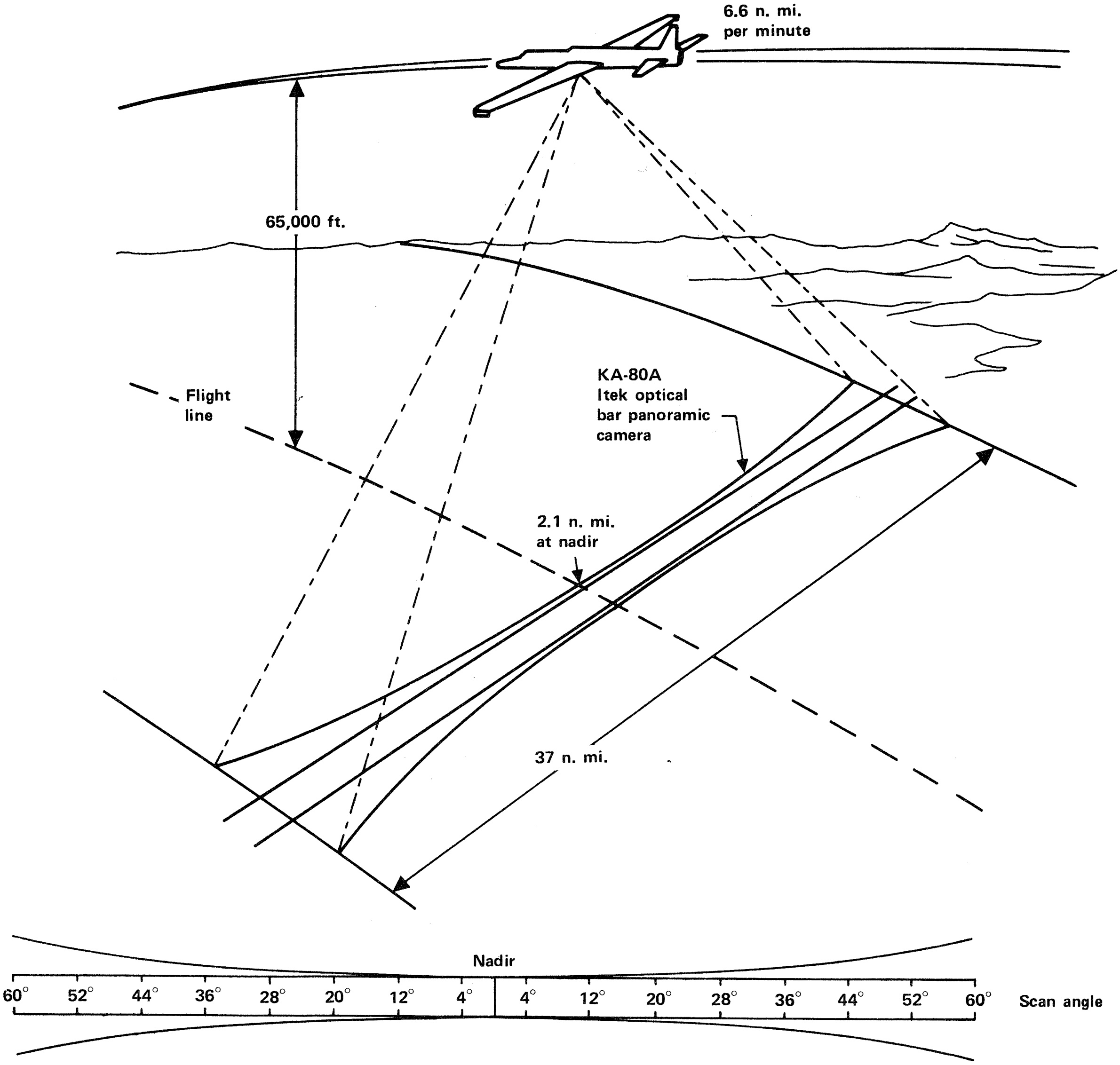

6.6 n. mi.
per minute
65,000 ft.
Flight
line
KA-80A
Itek optical
bar panoramic
camera
2.1 n. mi.
at nadir
37 n. mi.
Nadir
60° 52° 44° 36° 28° 20° 12° 4° 4° 12° 20° 28° 36° 44° 52° 60°
Scan angle

Figure A-1.- Ground coverage and scan angle for the Itek KA-80A optical bar panoramic camera.

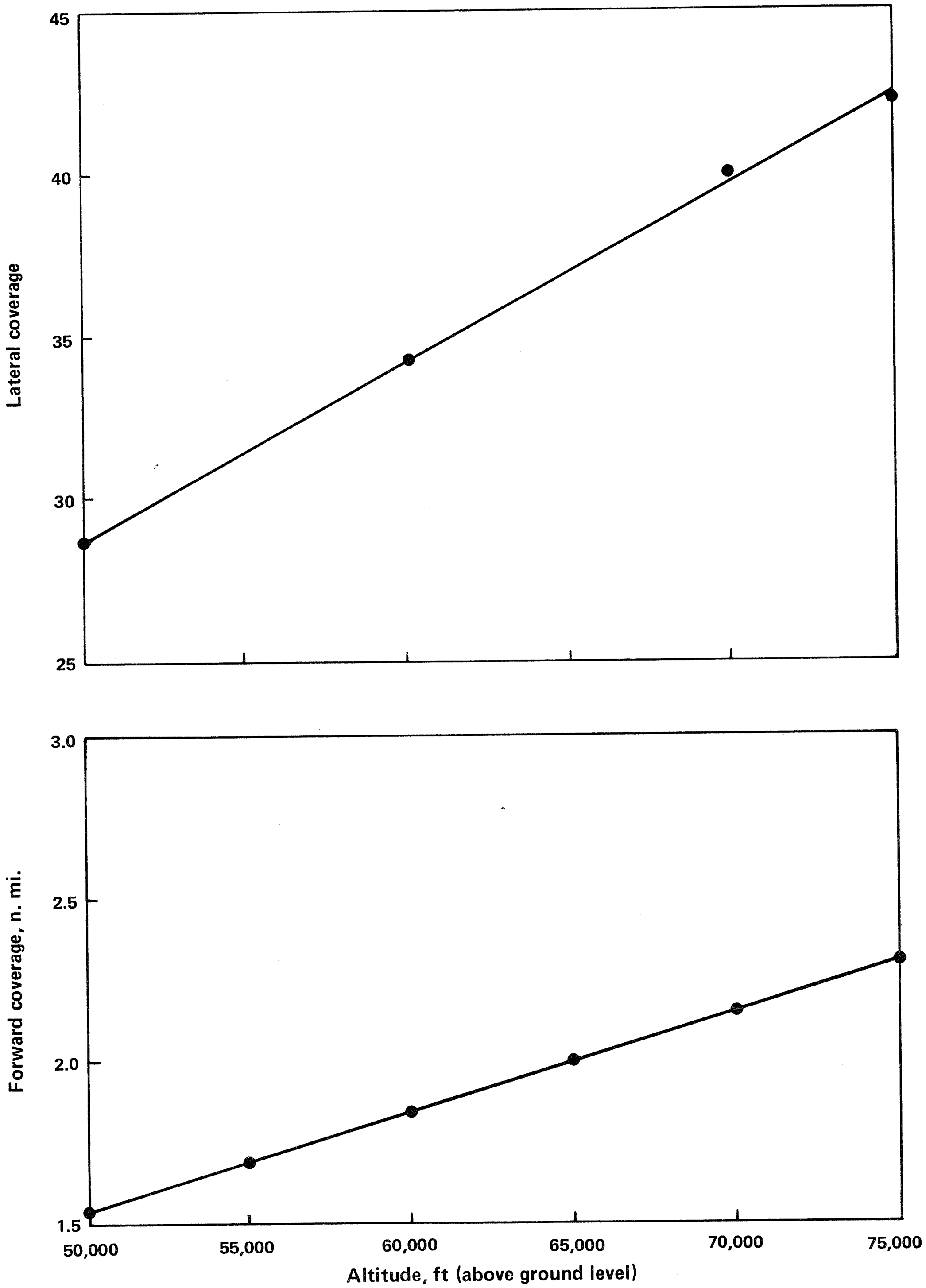


Figure A-2.- Forward coverage and lateral coverage for high-altitude panoramic photography (Itek KA-80A and IRIS II camera systems at 60° scan angle).

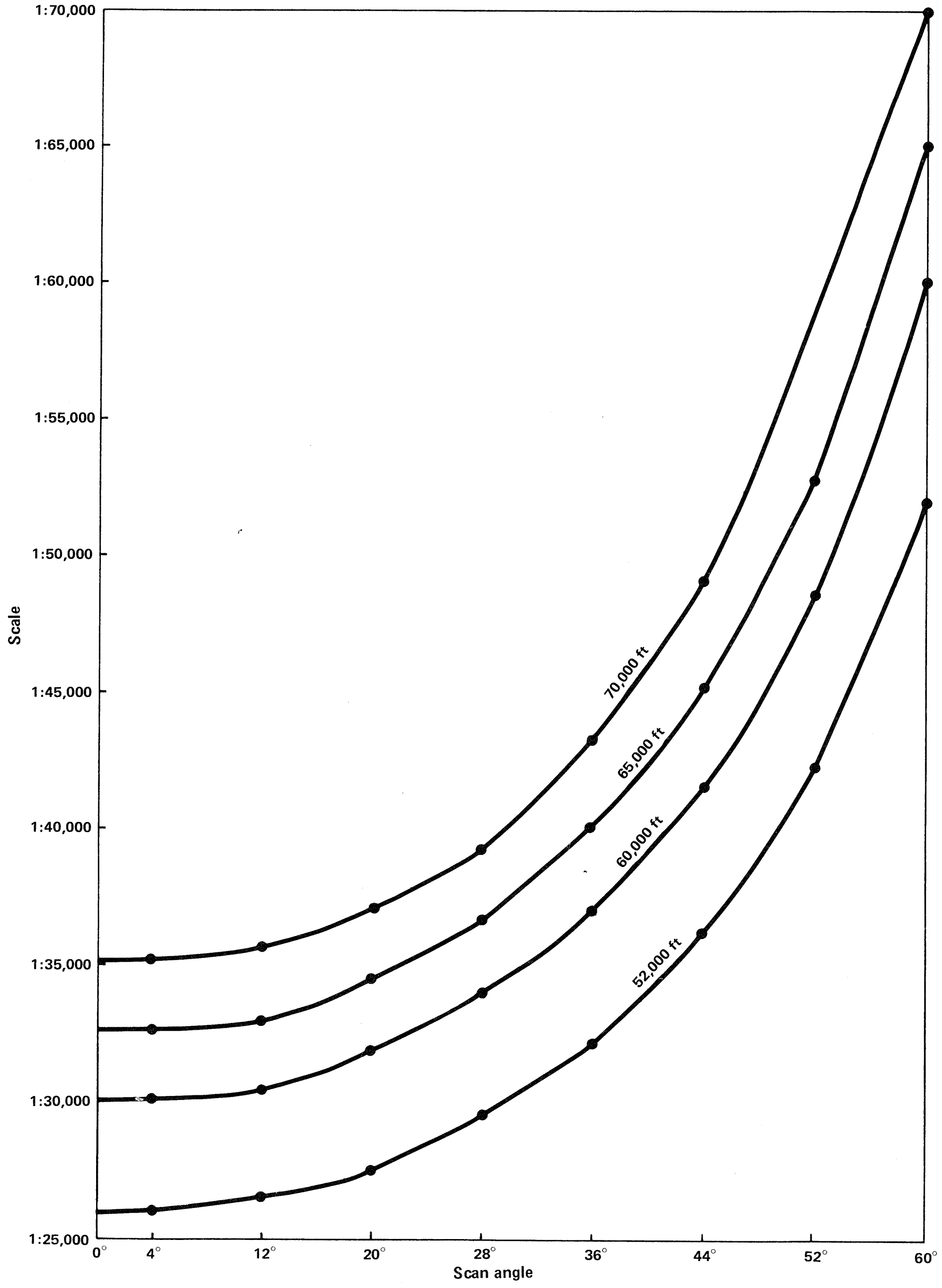


Figure A-3.- Photographic scale versus scan angle for high-altitude panoramic photography at four altitudes above ground level.

APPENDIX B

PHOTOINTERPRETER EXERCISES

This appendix presents three tests for the photointerpreter. A hidden word stereoscopic test and a stereoscopic vision test are provided in figures B-1 and B-2, respectively. Figure B-3 is a pest damage photointerpretation exercise. The correct answers for these tests are given on page B-6.

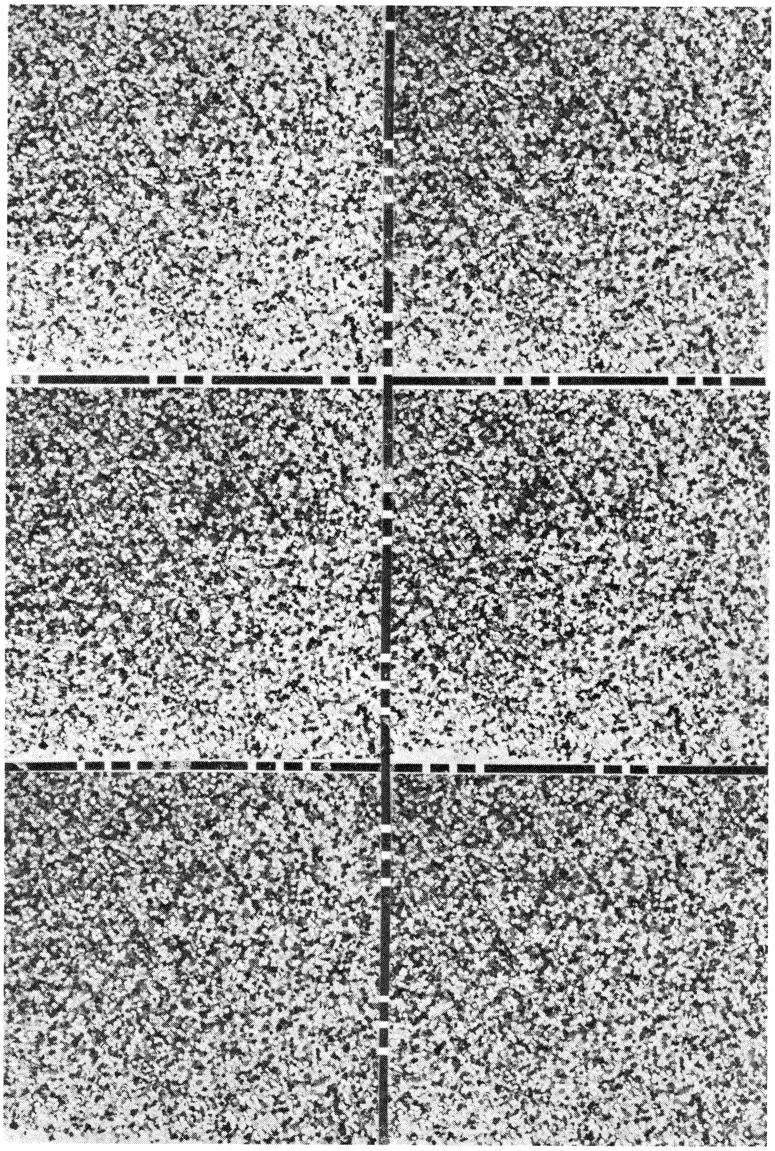


Figure B-1.- Hidden word stereoscopic test developed by Sims and Hall. [Sims, W. G.; and Hall, Norman: The Testing of Candidates for Training as Airphoto Interpreters. Forestry and Timber Bureau, Common Wealth of Australia (Canberra), 1956.]

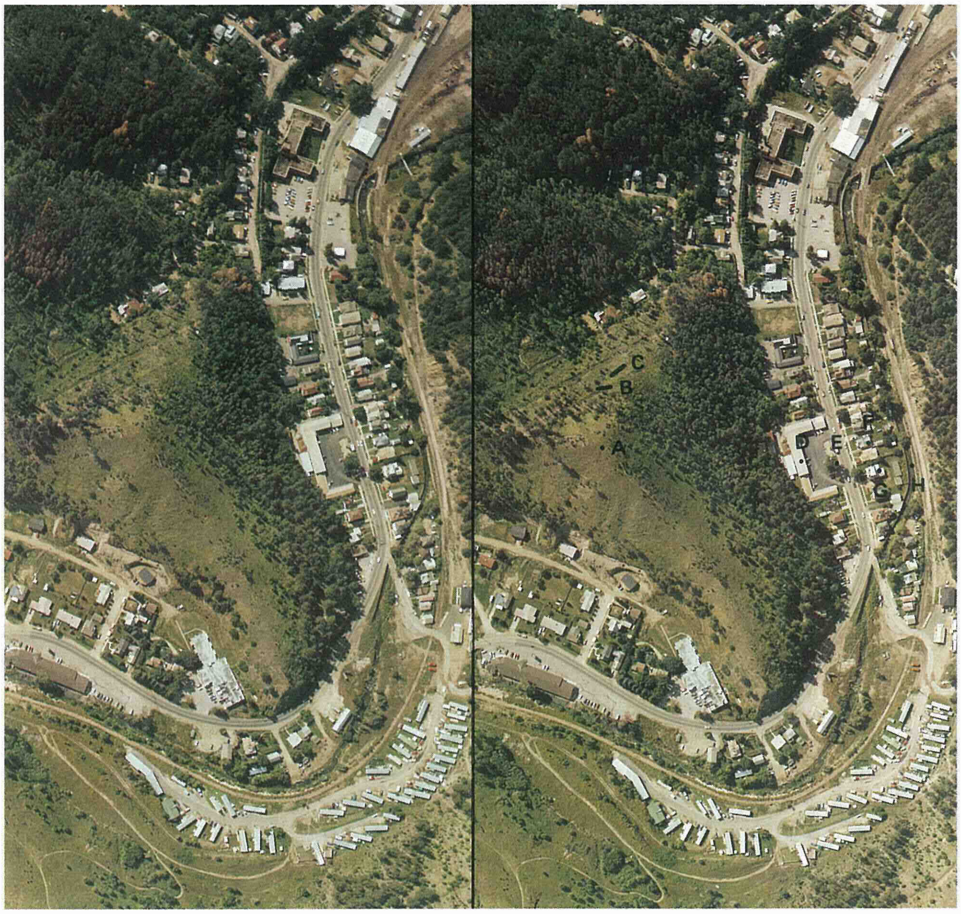
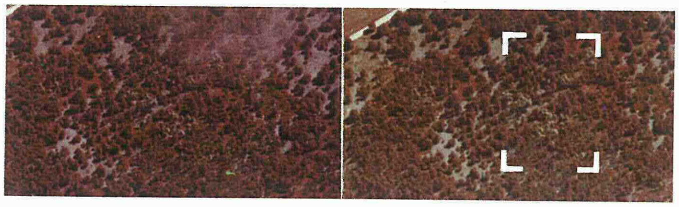
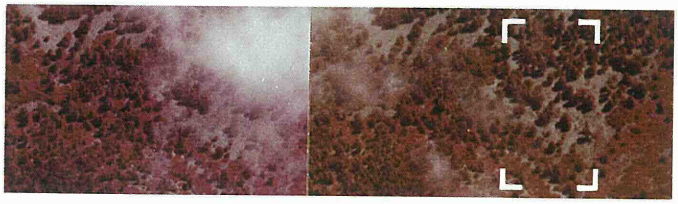


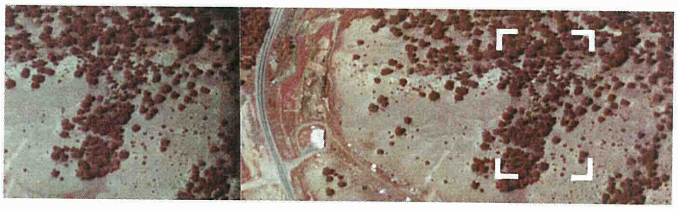
Figure B-2.- Stereoscopic vision test using a stereogram of Lead, South Dakota (scale: ≈1:6000). Position a stereoscope over the figure and rank the annotated objects according to height (highest = 1, second highest = 2, and so on).



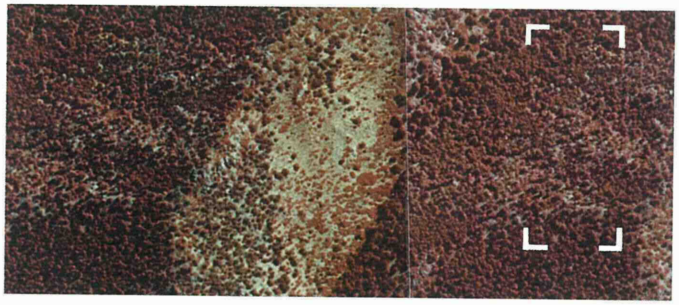
(a) Plot 1236-1-37, B2



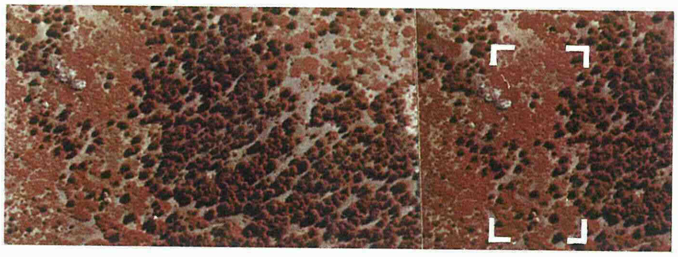
(b) Plot 1236-1-37, G3



(c) Plot 1236-2-9, A2

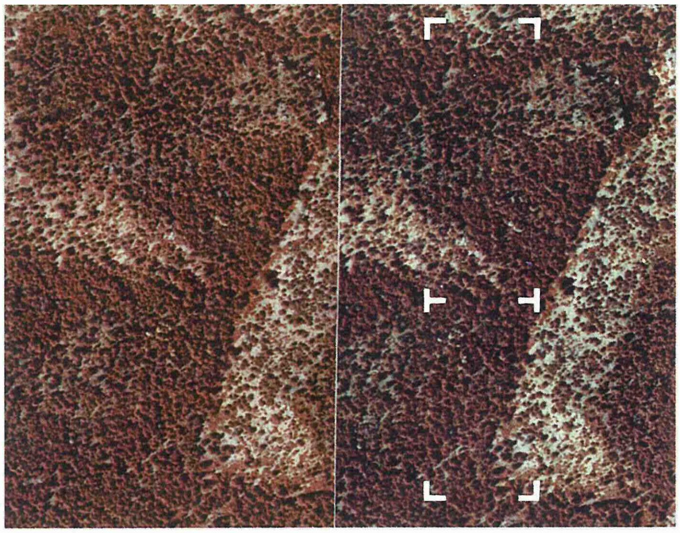


(d) Plot 1210-4-28, G1

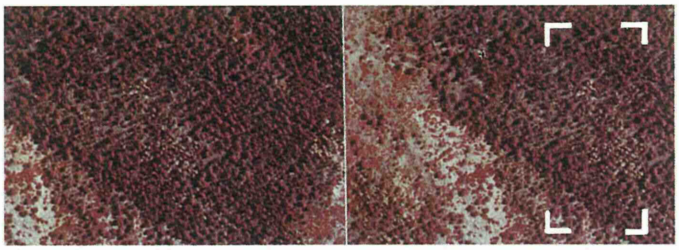


(e) Plot 1210-2-28, C3

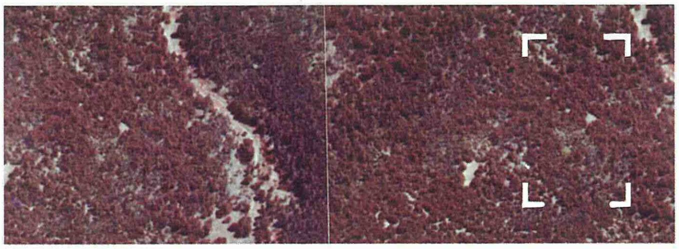
Figure B-3.- Photointerpretation exercise using photography from the Colorado Front Range. A lens stereoscope is to be used to count the number of current-year ponderosa pine faders in each plot.



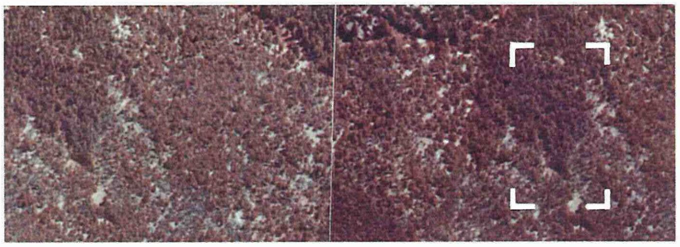
(f) Plot 1210-3-26, C4 (g) Plot 1210-3-27, C1



(h) Plot 1228-4-16, E1



(i) Plot 1416-1-36, A1



(j) Plot 1416-2-37, E2

Figure B-3.- Concluded.

ANSWERS

For figure B-1:

Words

Father - Sun
Soft - Smoot
Fir

For figure B-2:

Object	Ranking
A	1
B	2
C	3
D	6
E	4
F	7
G	5
H	8

For figure B-3:

Plot	Number* of faders
a	64
b	1
c	12
d	20
e	2
f	3
g	12
h	163
i	24
j	6

*Based on field evaluation.

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